# Subsurface Gravel Wetlands for the Treatment of Stormwater

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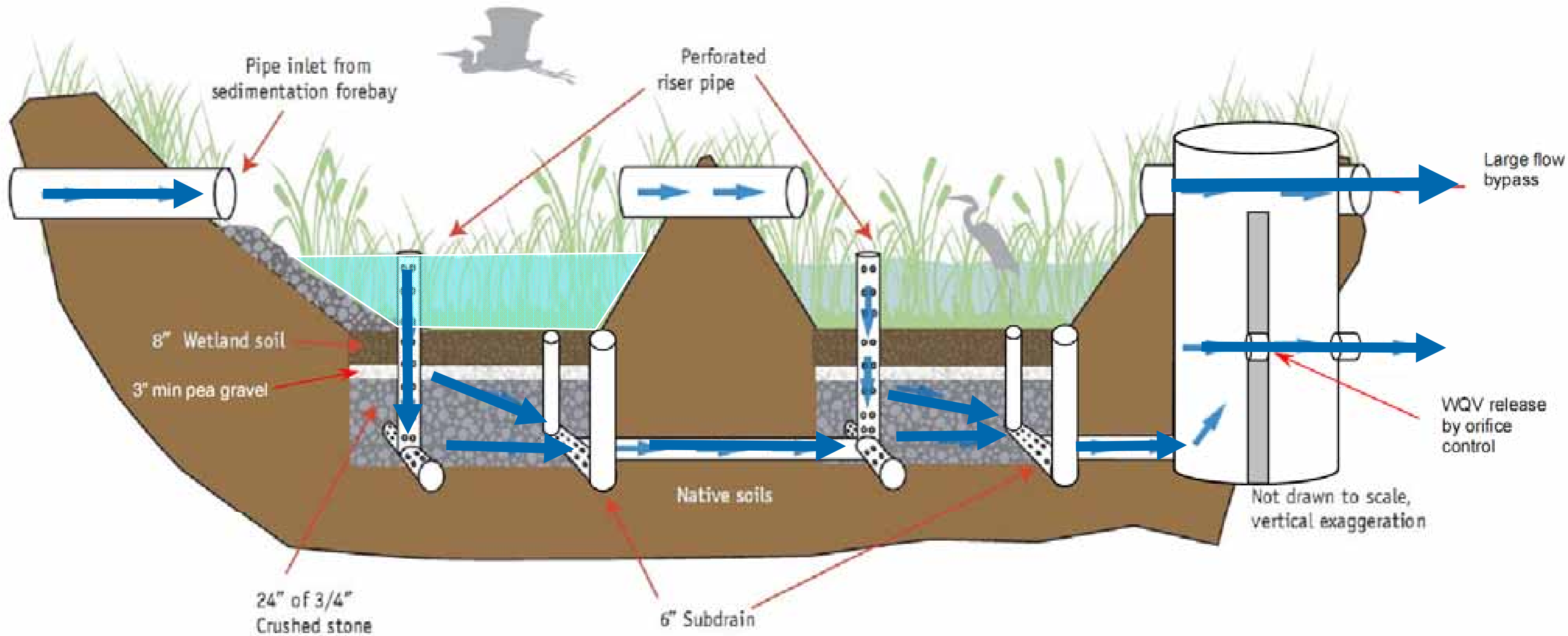
*Dedicated to the protection of water resources through effective stormwater management*

- Research and development of stormwater treatment systems
- To provide resources to stormwater communities currently involved in design and implementation of Phase II requirements

- Brief introduction to subsurface gravel wetlands and their hydraulic performance.
- Water quality performance, especially nutrient nitrogen
- Design aspects
- Plants
- Costs and comparisons
- Case studies

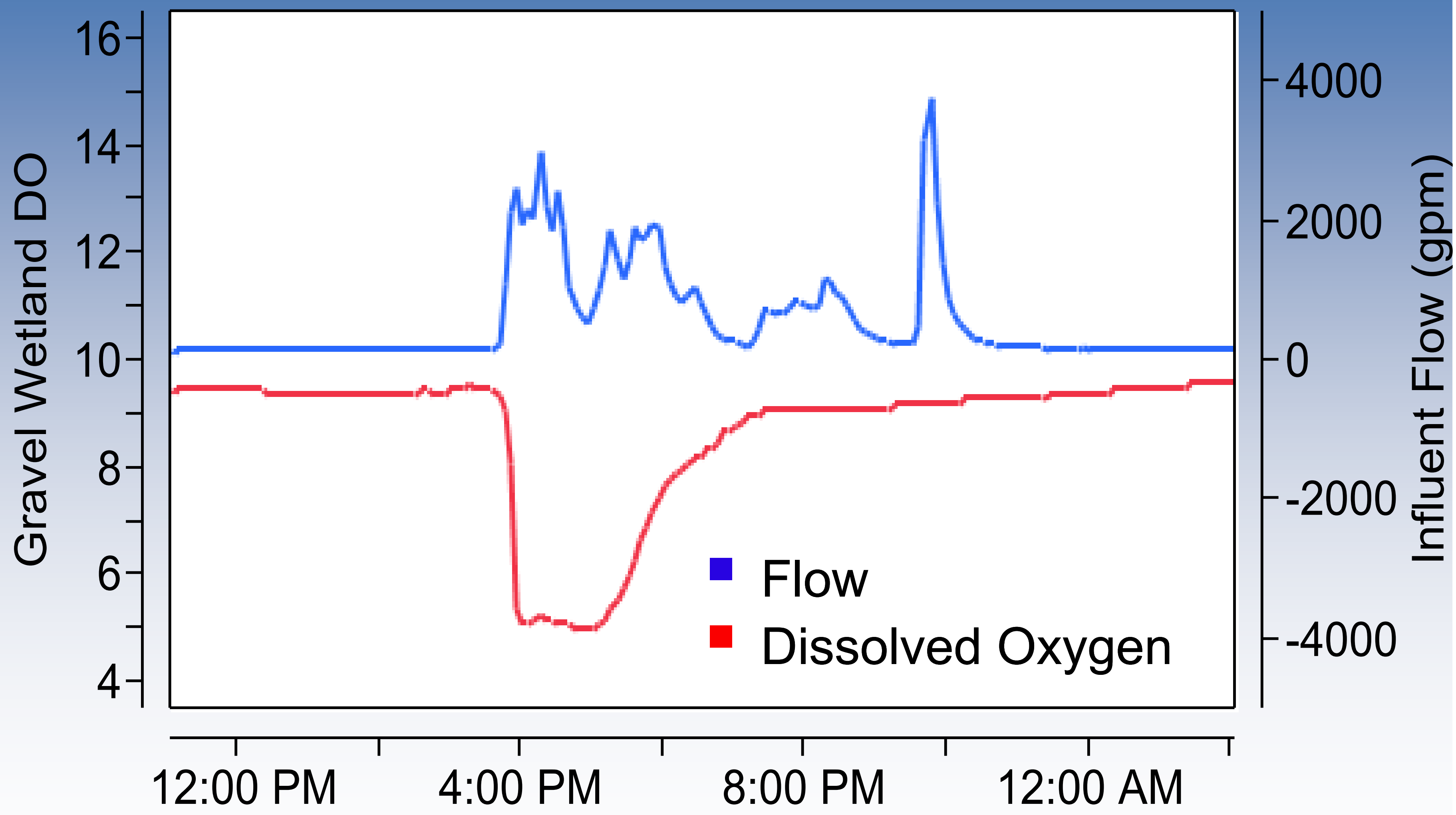
# Gravel Wetland

# Subsurface Gravel Wetland




Design Sources:
Claytor, R. A., and Schueler, T. R. (1996). Design of Stormwater Filtering Systems, Center for Watershed Protection, Silver Spring, MD.
Georgia Stormwater Management Manual, Volume 2: Technical Handbook, August 2001, prepared by AMEC Earth and Environmental, Center for Watershed Protection, Debo and Associates, Jordan Jones and Goulding, Atlanta Regional Commission.

# Dissolved Oxygen in Gravel Wetland Effluent



Nitrification

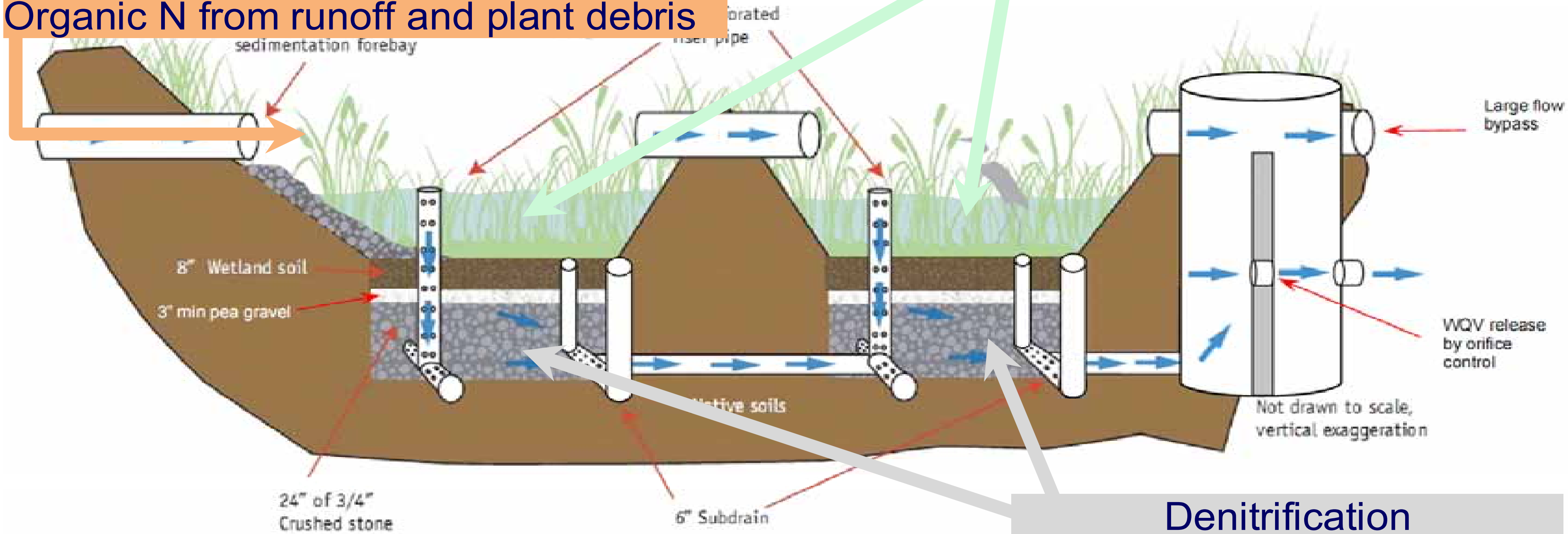
$NH_4 \rightarrow N0_2 \rightarrow NO_3$

Aerobic Zone

Forebay and surface of wetland

Influent

Organic N from runoff and plant debris

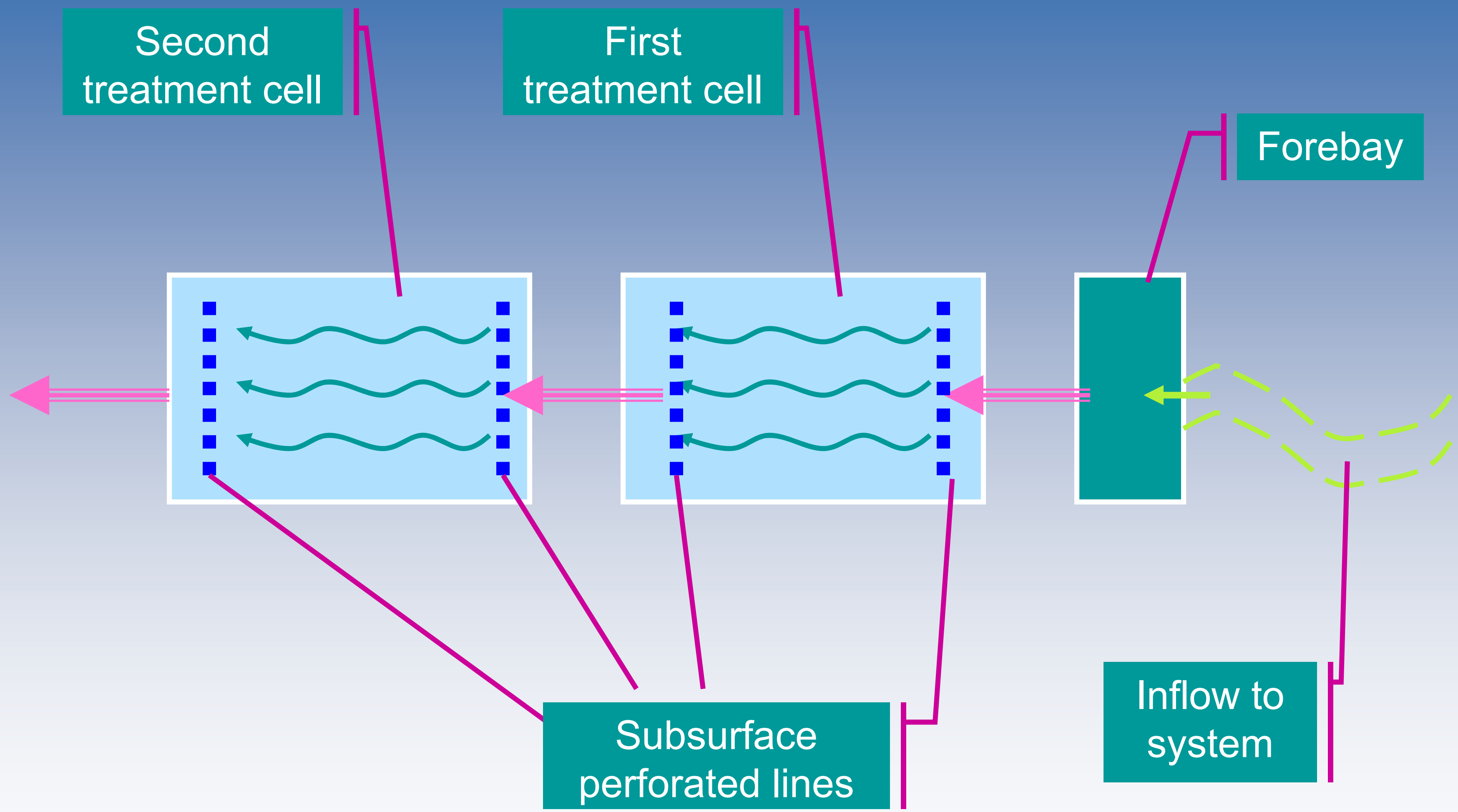



Denitrification

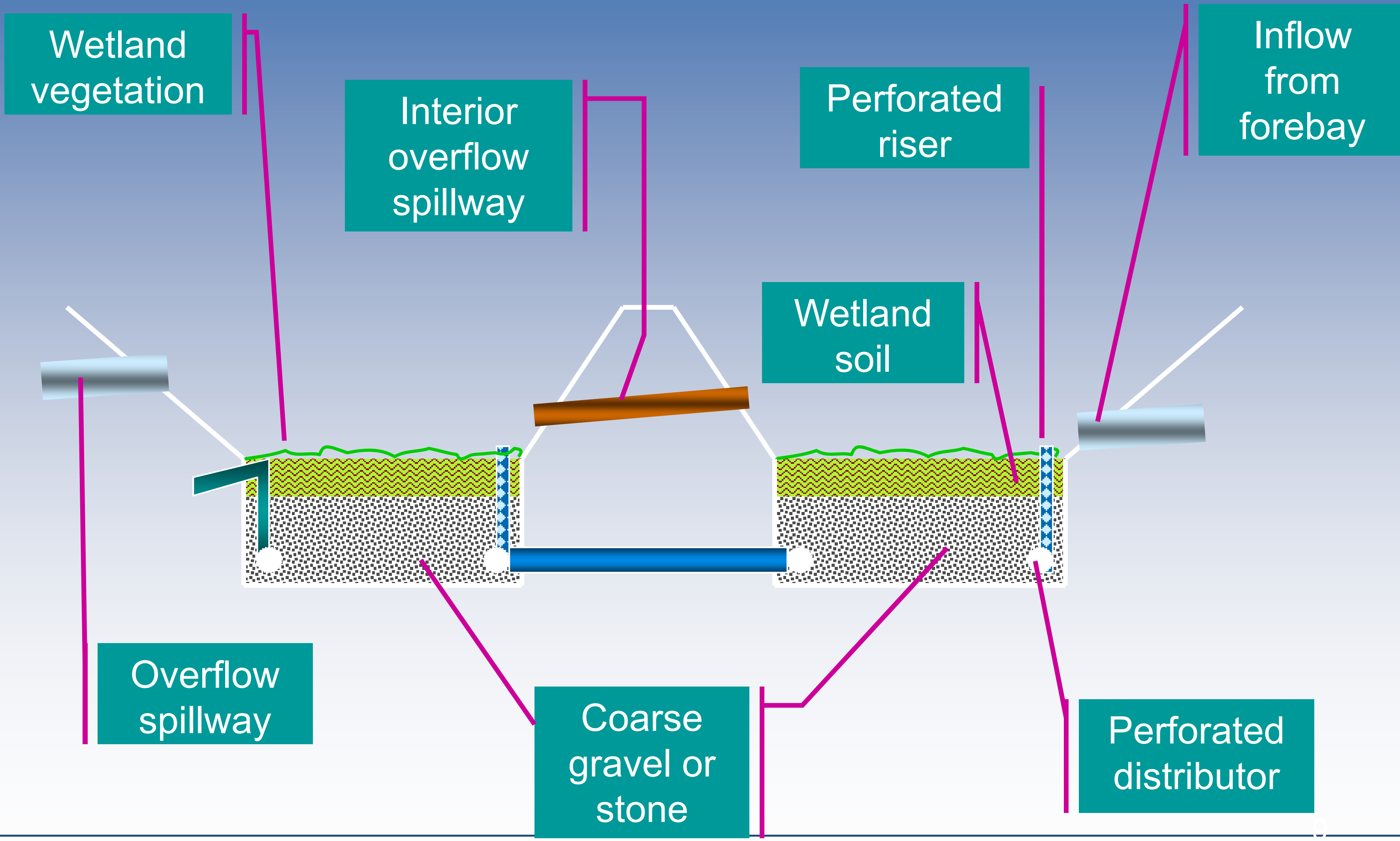
$\rightarrow N_2$ (gas)

Anaerobic Zone

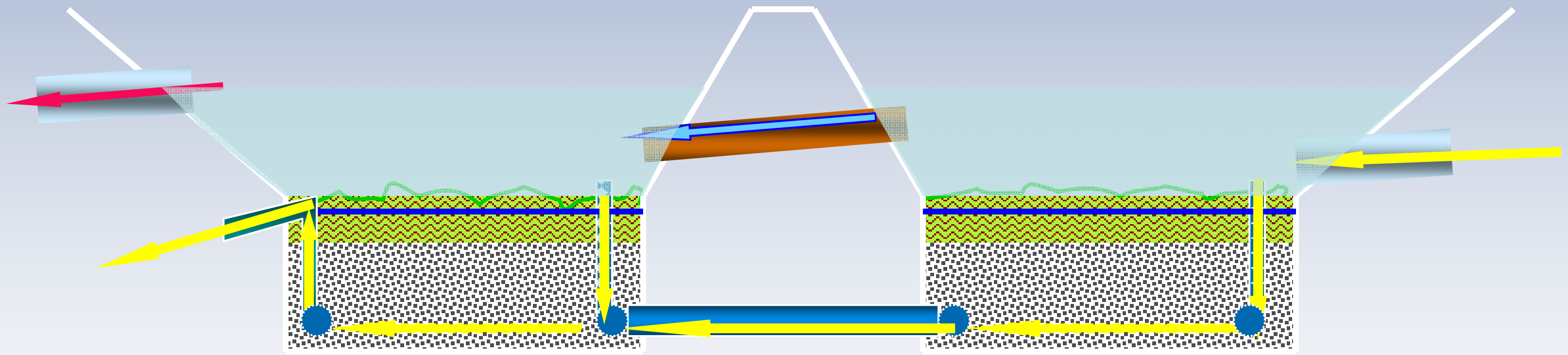
Subsurface gravel


Second treatment cell
First treatment cell
Forebay
Subsurface perforated lines
Inflow to system

# The UNH SC Subsurface Gravel Wetland Design



# Flow Through the Subsurface Gravel Wetland Design



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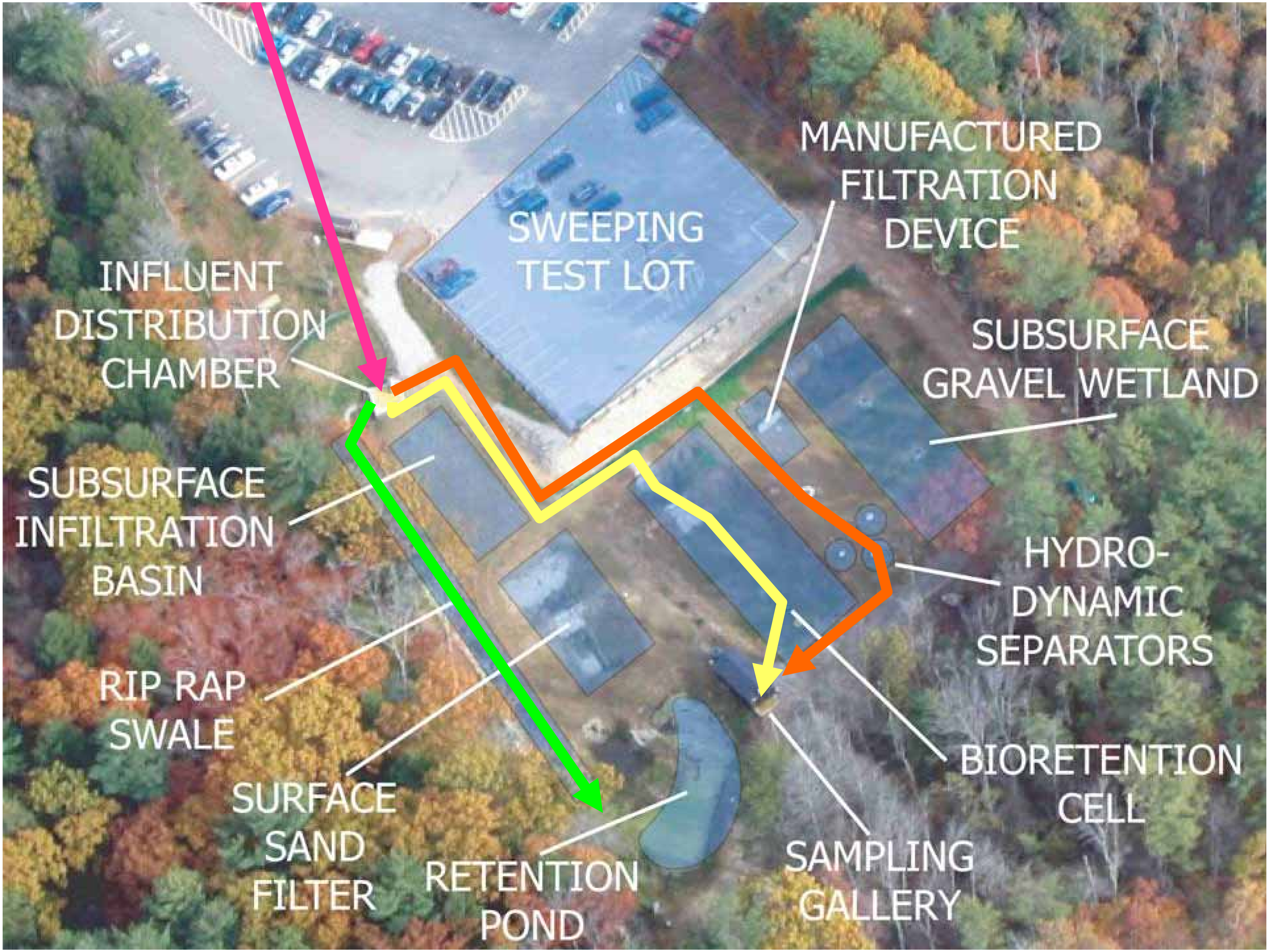
# BMP Performance Monitoring

## Research Field Facility at UNH

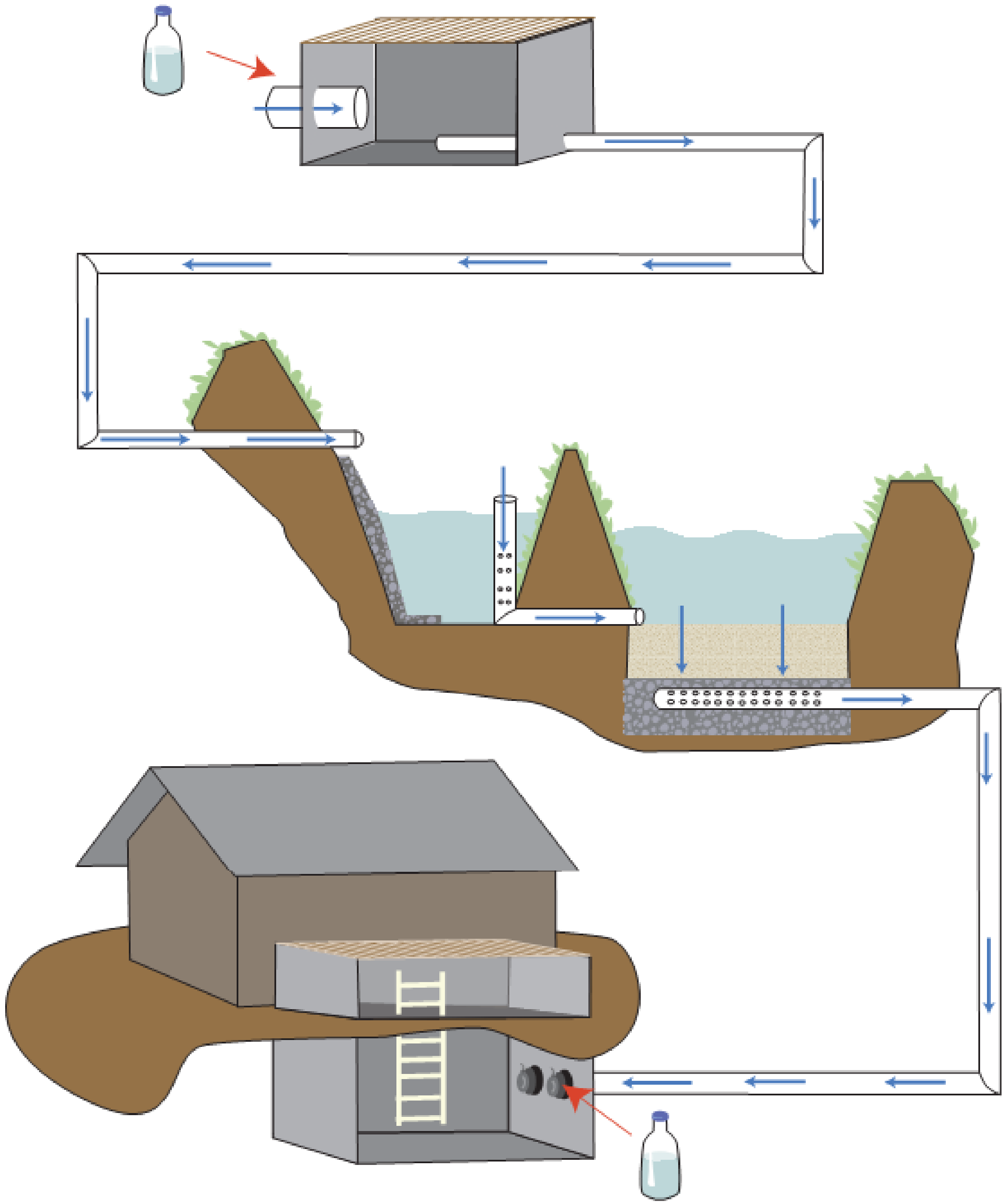
**Tc ~ 19 minutes**



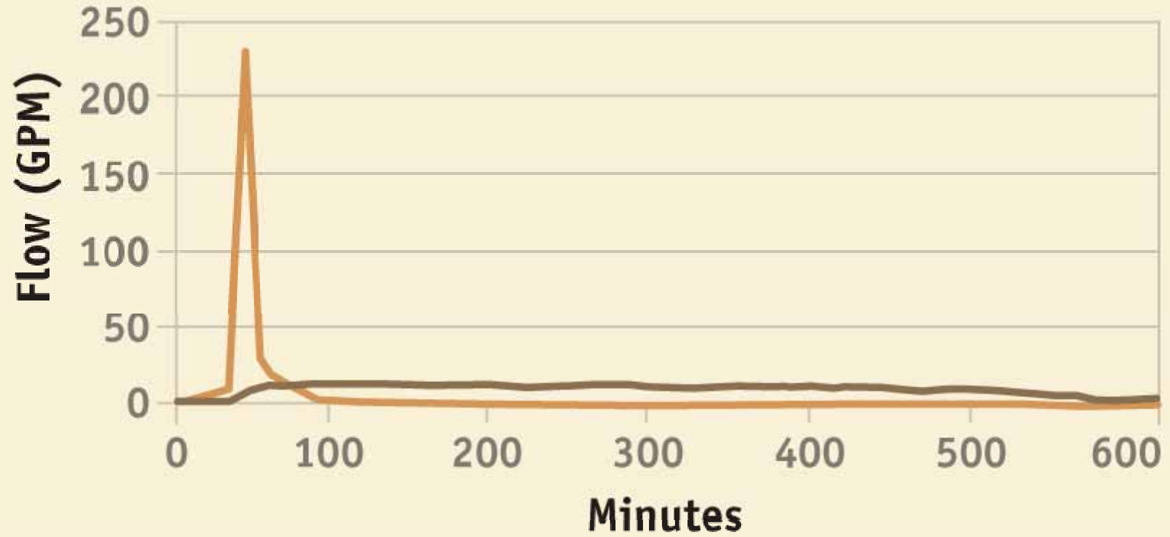
SWEEPING TEST LOT
MANUFACTURED FILTRATION DEVICE
INFLUENT DISTRIBUTION CHAMBER
SUBSURFACE GRAVEL WETLAND
SUBSURFACE INFILTRATION BASIN
HYDRO-DYNAMIC SEPARATORS
RIP RAP SWALE
BIORETENTION CELL
SURFACE SAND FILTER
RETENTION POND
SAMPLING GALLERY

# Parallel Performance Evaluation

- Each system uniformly sized to treat 1" runoff for 1 acre of impervious area
- WQV=3300 cf
- $Q_{wqv}$=1 cfs
- Uniform contaminant loading
- Uniform storm event characteristics
- Systems lined for mass balance
- Long term record of hydrology and contaminants

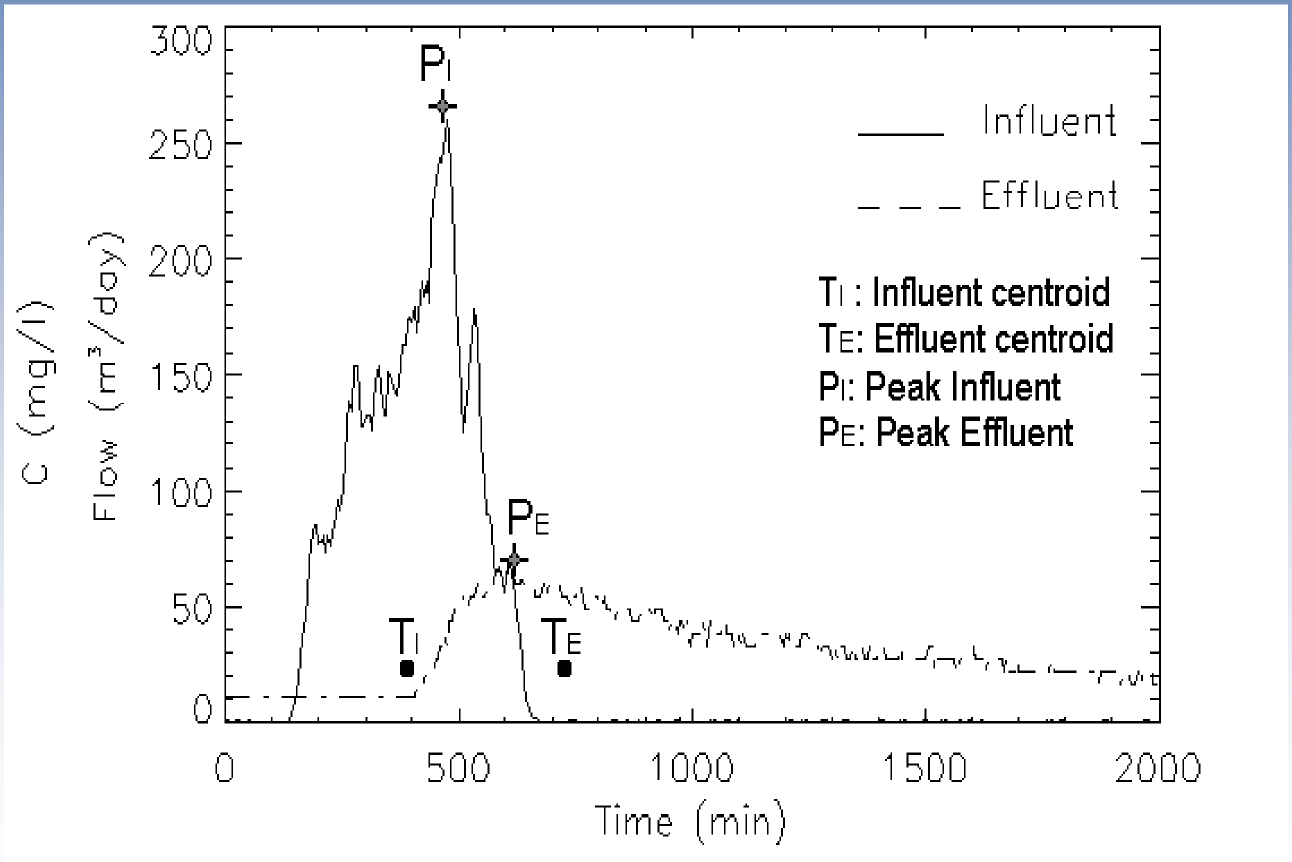


# Subsurface Gravel Wetland Hydraulic Performance




| | Winter | Summer | Annual Average |
|---|---|---|---|
| Average Peak Flow Reduction | 85% | 77% | 81% |
| Average Lag Time (minutes) | 318 | 313 | 315 |

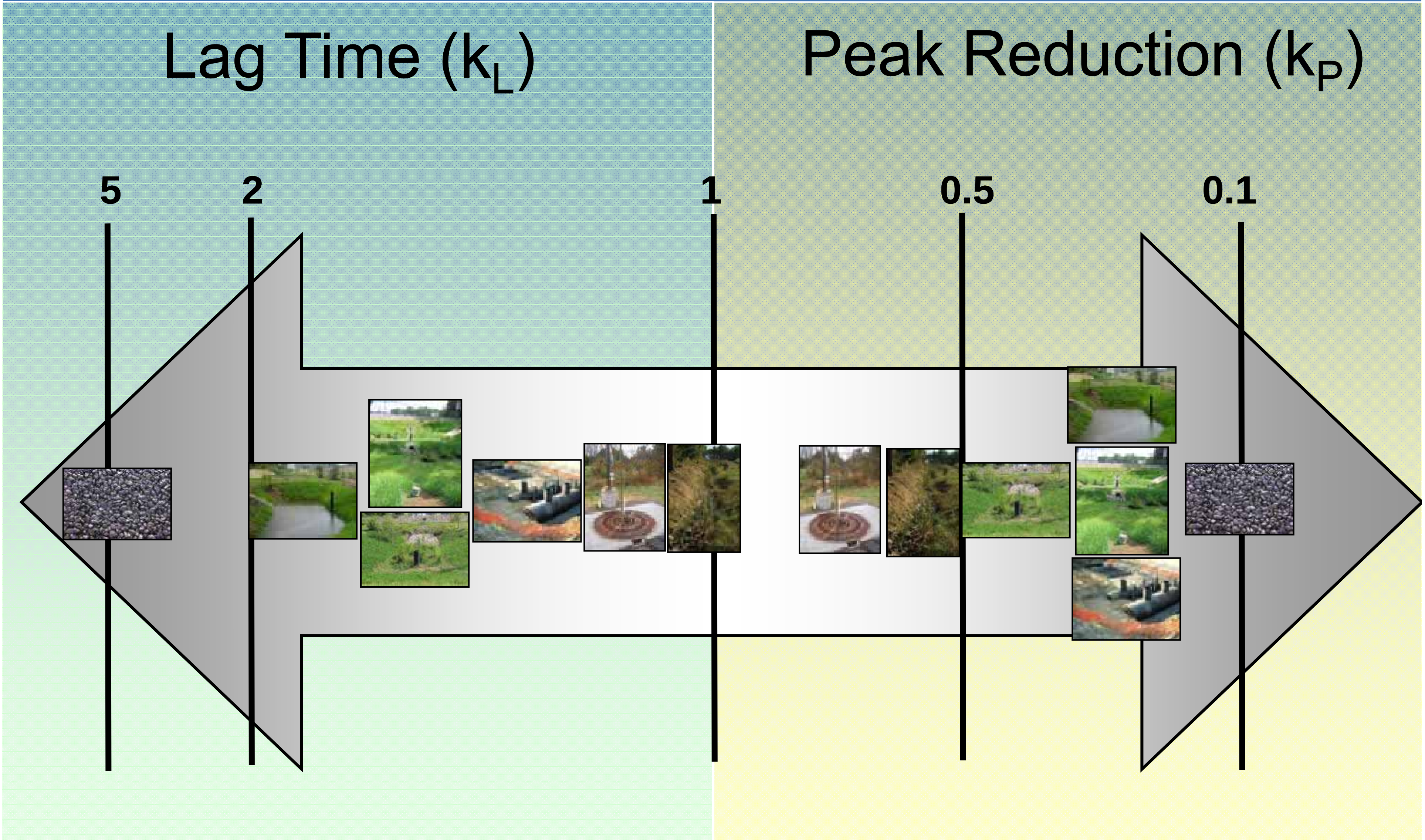
# Hydraulic Efficiency



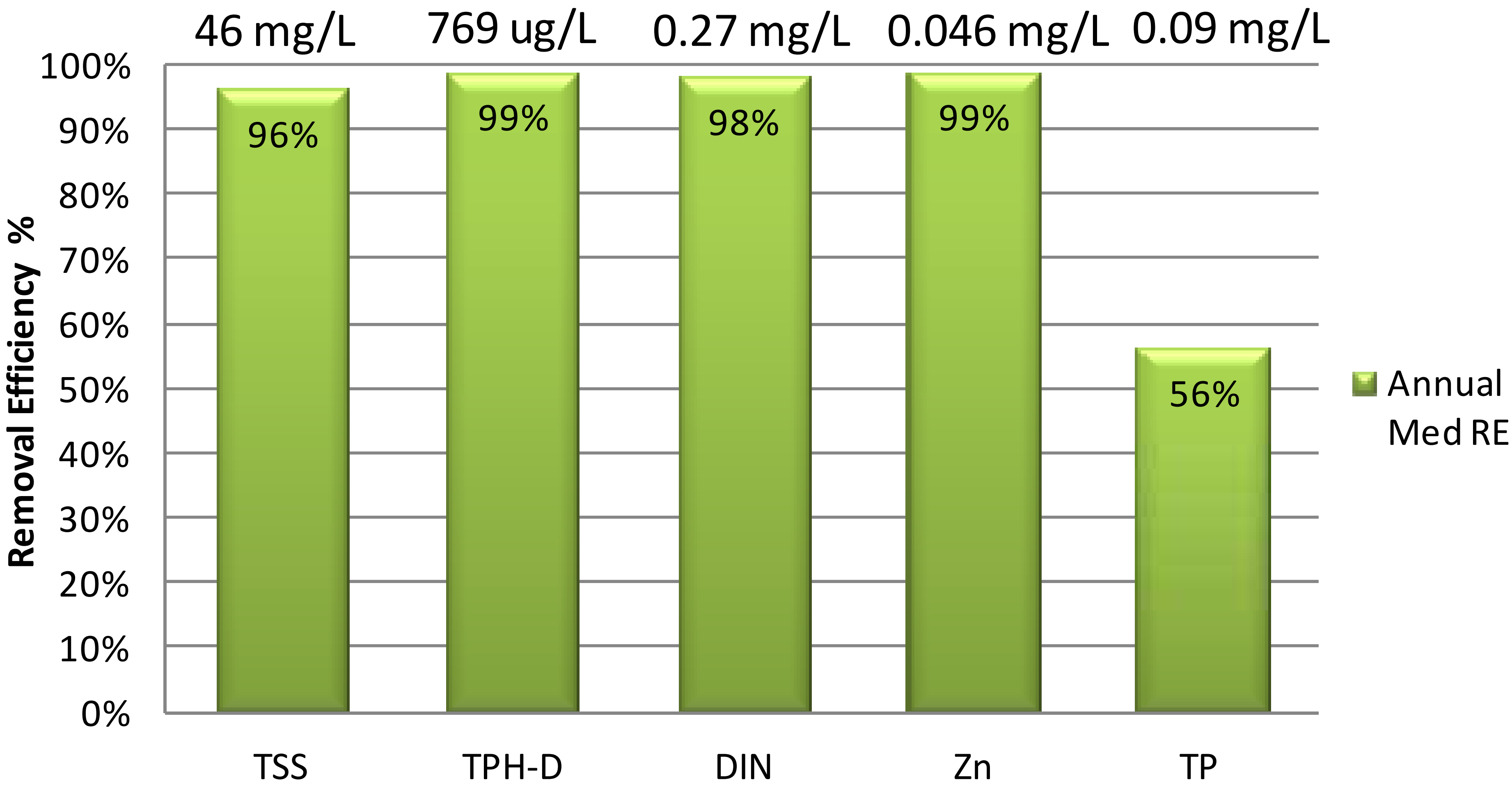

$$k_p = \frac{P_E}{P_I} \leq 1$$

$$k_L = \frac{T_E}{T_I} \geq 1$$

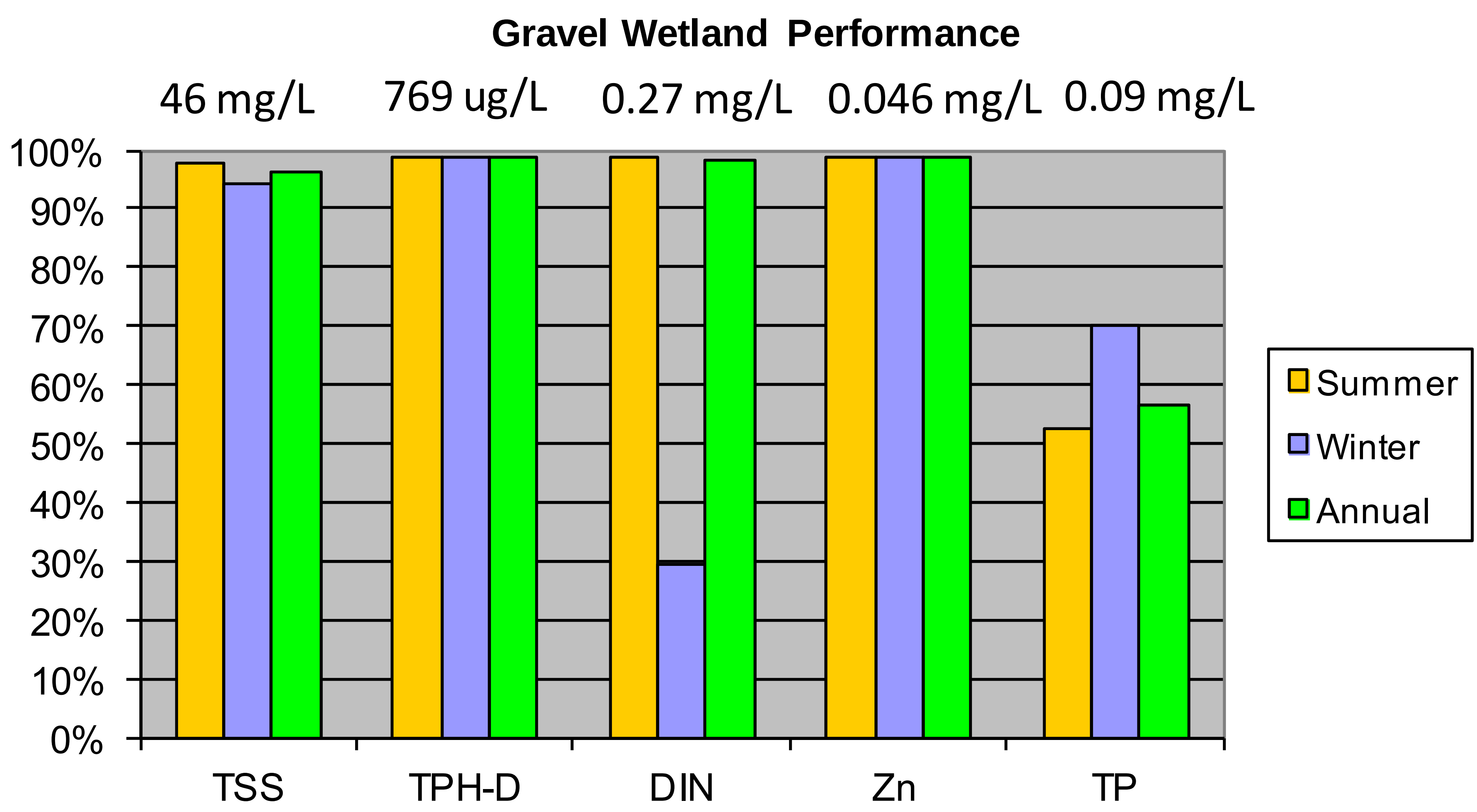
# Hydraulic Performance



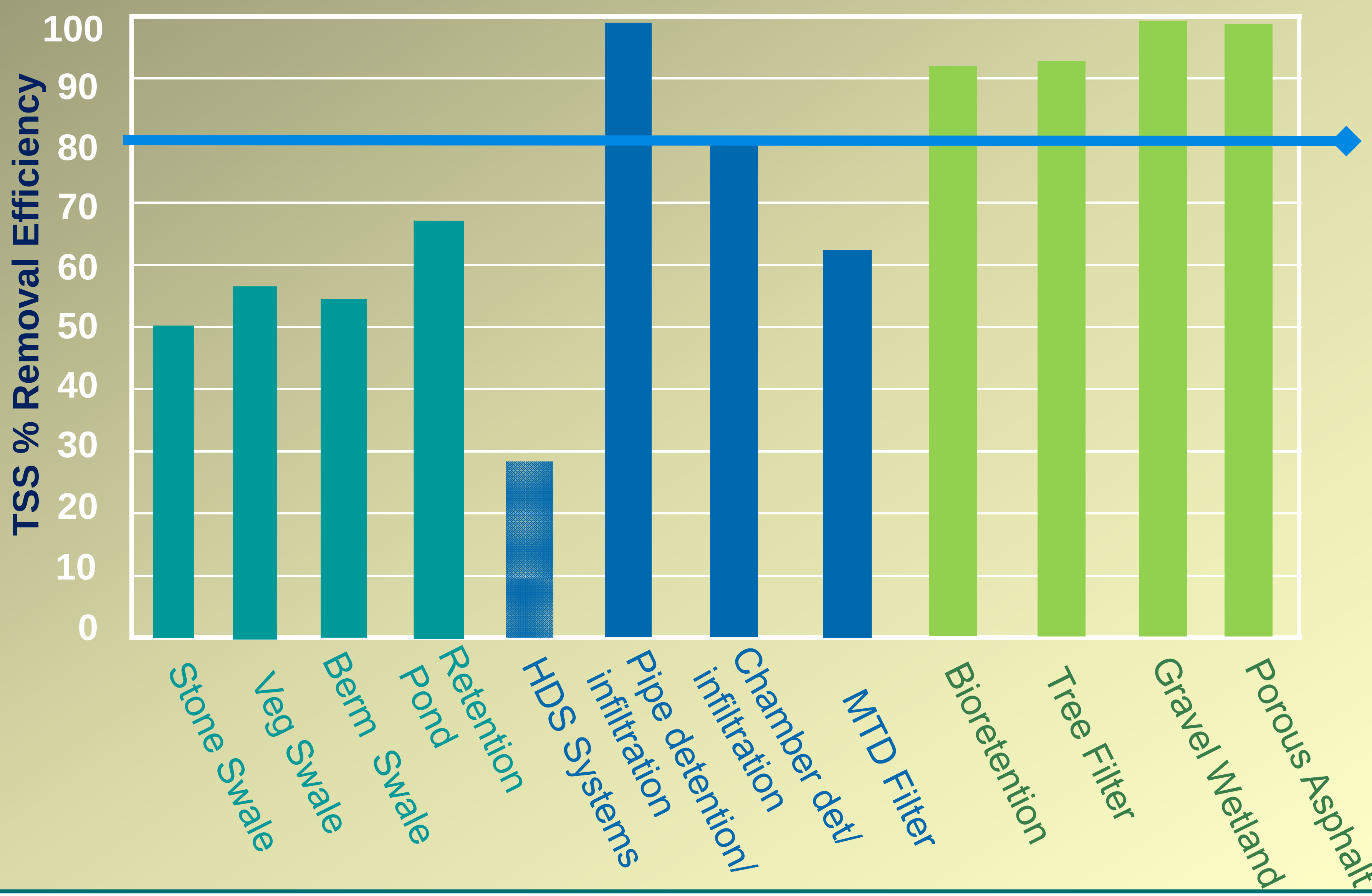
# Gravel Wetland Performance



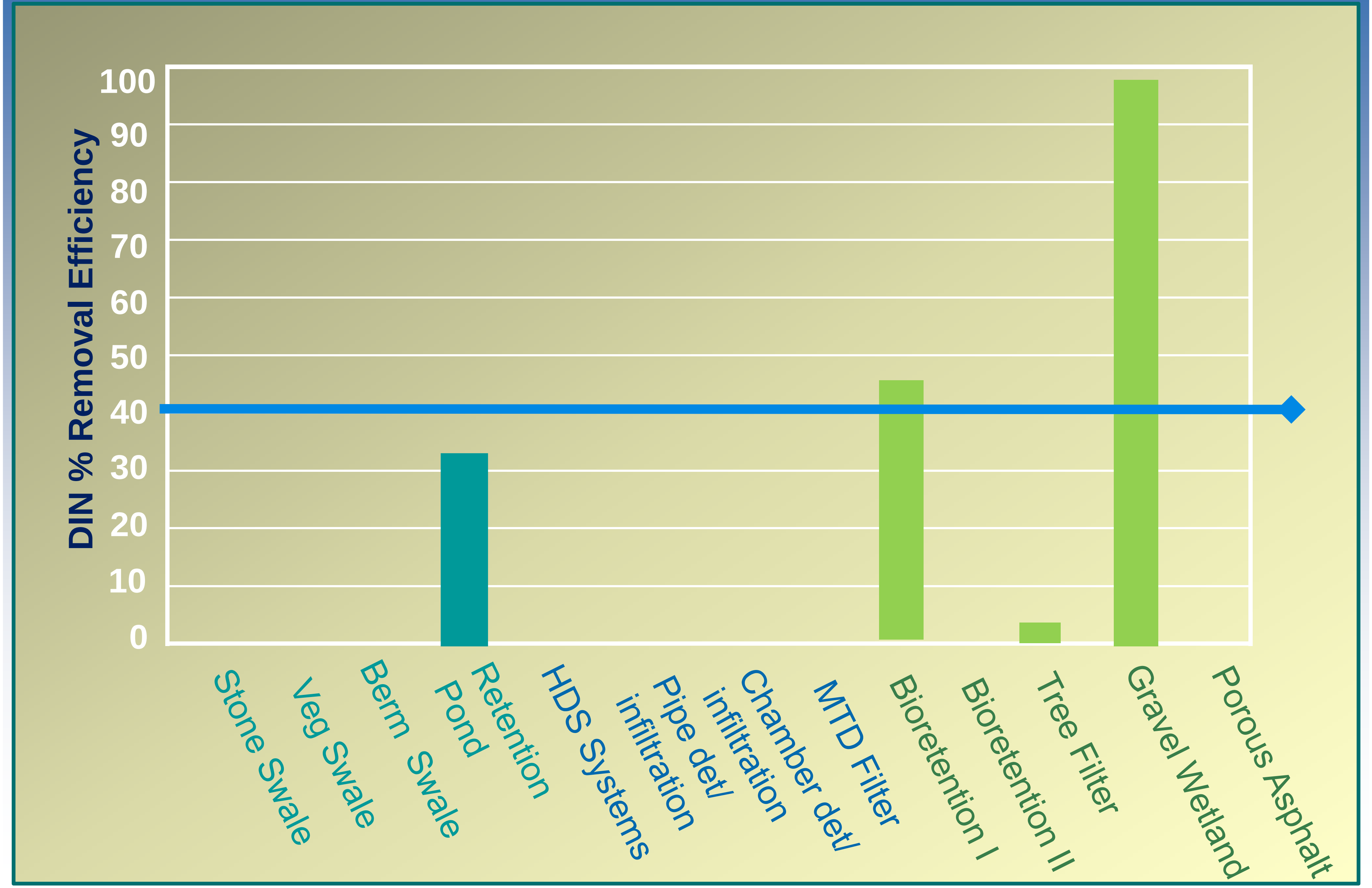
# Seasonal Performance



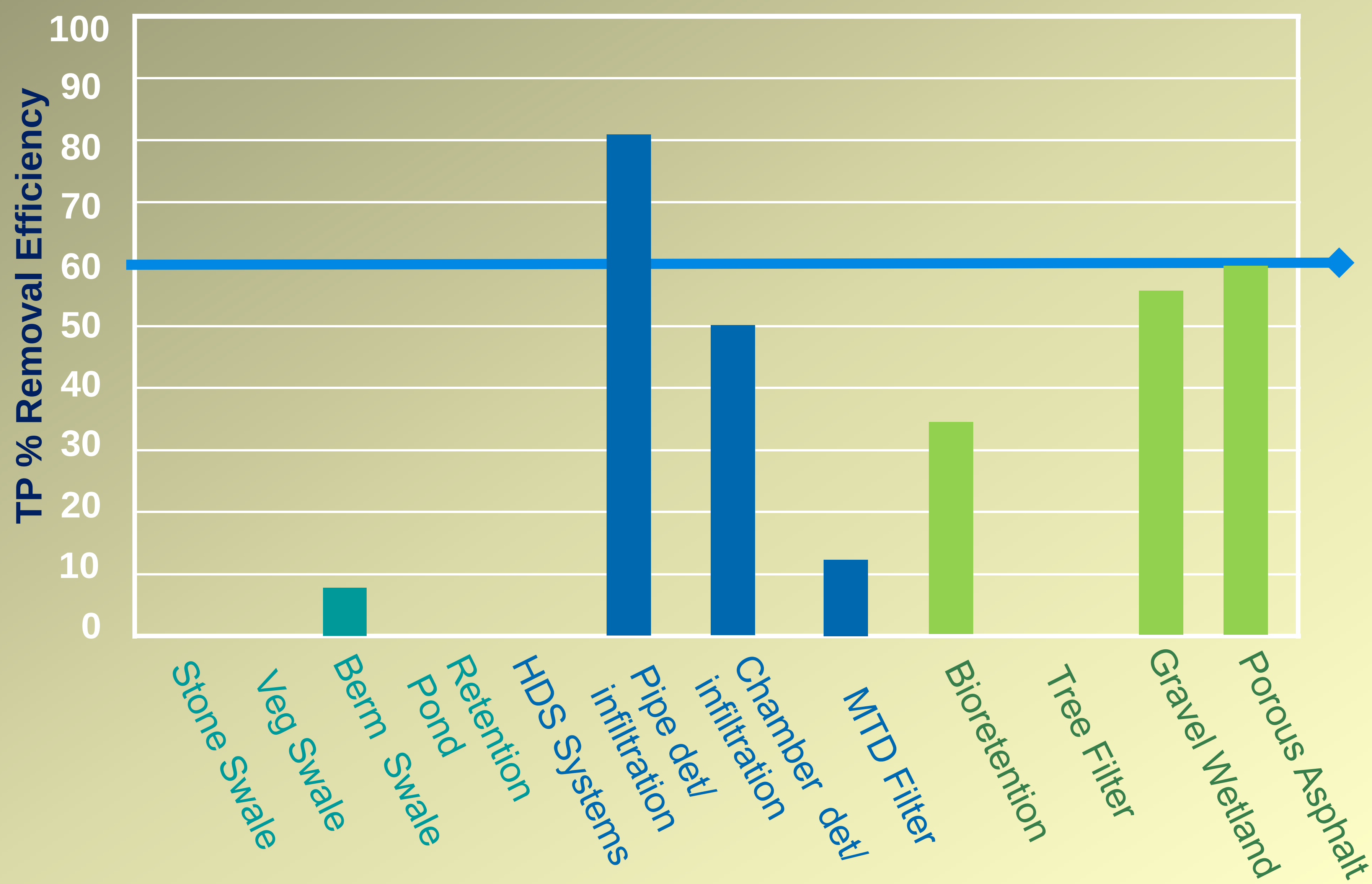
# TSS Removal Efficiencies



# DIN Removal Efficiencies



# TP Removal Efficiencies



# Unit Operations & Processes (UOPs) in the Gravel Wetland

- Physical Operations
- Biological Processes
- Chemical Processes
- Hydrologic Operations

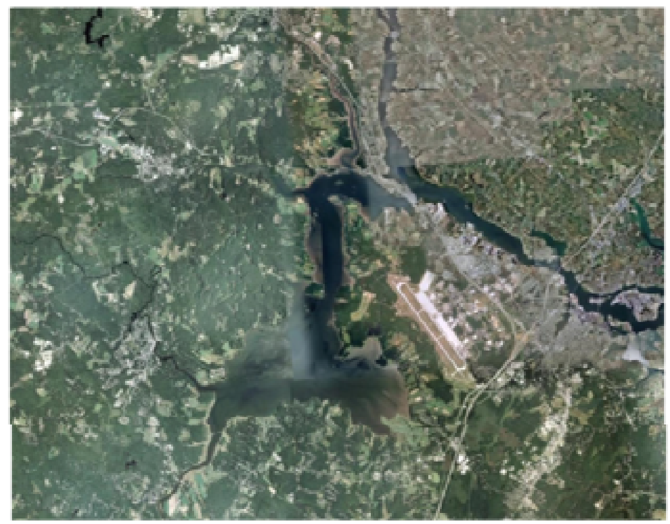
# Gravel Wetland Report Card

| category | uop | target | "grade" |
|---|---|---|---|
| hydrologic | flow alteration | divert flow | ✓ |
| | volume reduction | | |
| physical | sedimentation | sediment | ✓ |
| | enhanced sedimentation | sediment | |
| | filtration | sediment | ✓ |
| biological | microbial | nitrogen | ✓+ |
| | vegetative | nitrogen<br>phosphorus | ✓+ |
| chemical | sorption | phosphorus | ✓ |

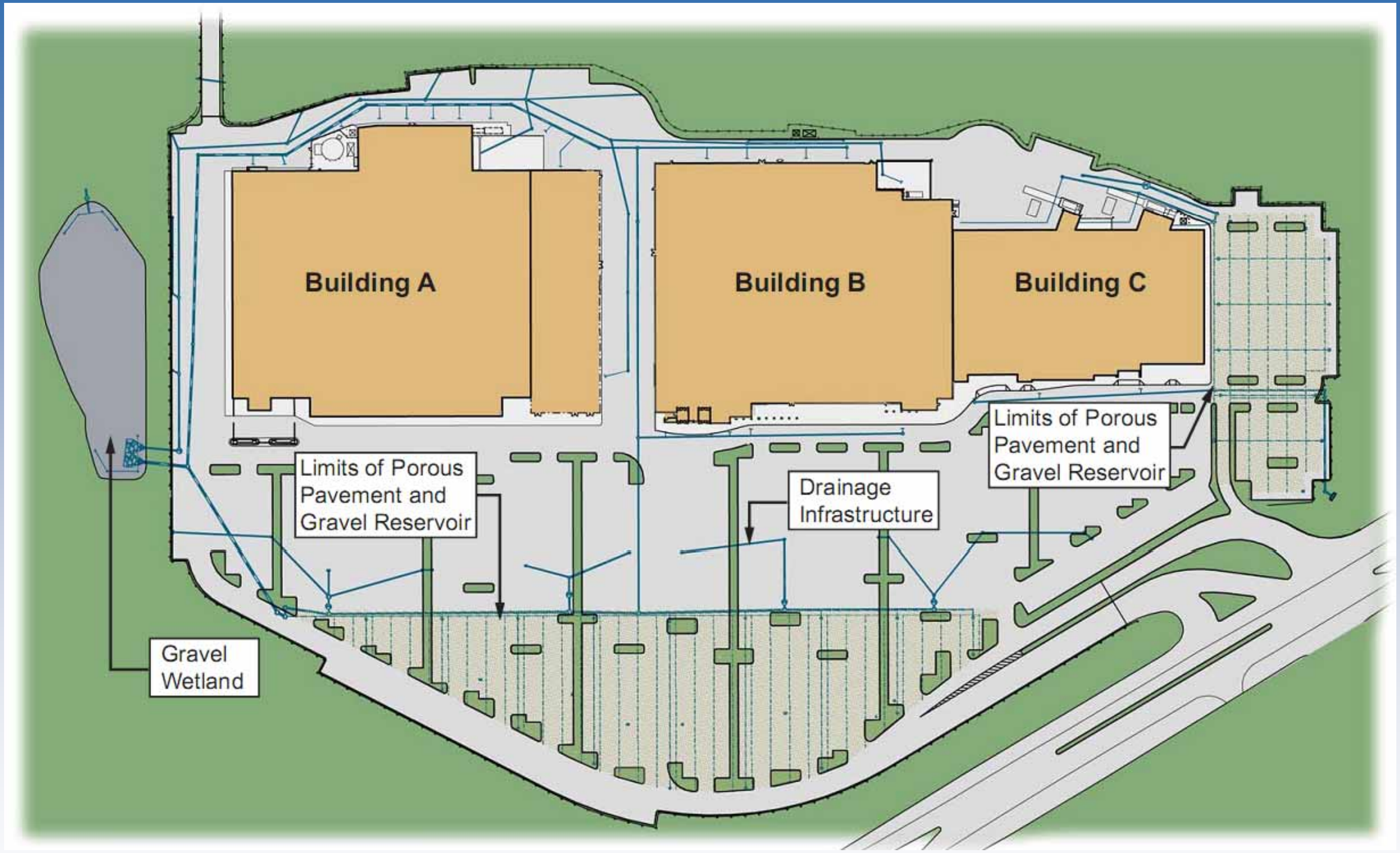

Example Retrofit in the
Northeast

# Greenland Meadows Commercial

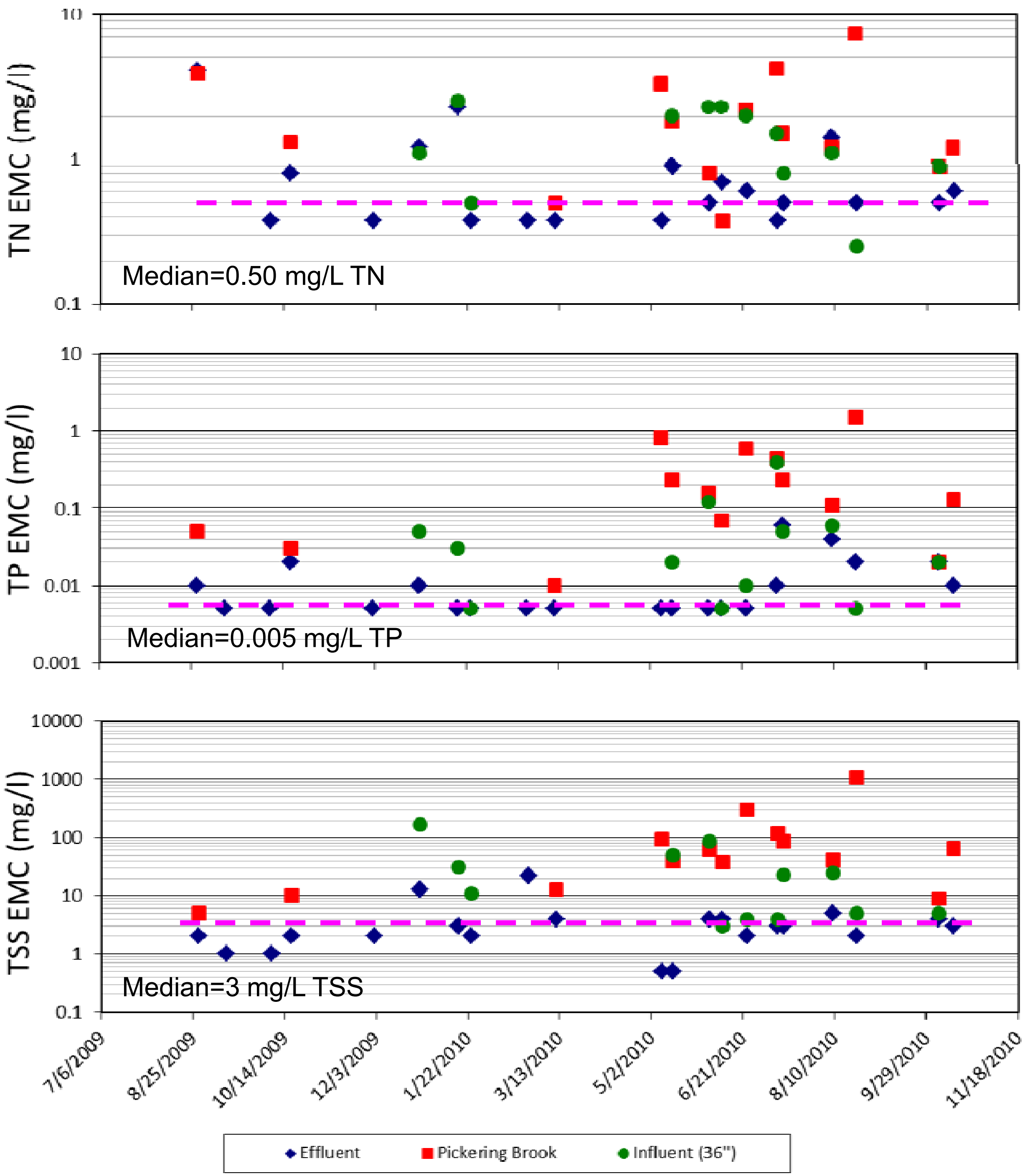
- "Gold-Star" Commercial Development
- Cost of doing business near Impaired Waters/303D
- Saved $800k in SWM on costly piping and advanced SWM proprietary ($3.3M vs $2.5M)
- Brownfields site, ideal location, 15yrs
- Proposed site >15,000 Average Daily Traffic count on >30 acres



# Site Design using LID and MTD




28 ac site, initially >95% impervious, now <10%EIC, with all drainage through filtration, expected to have minimal WQ impact except thermal and chloride


TN EMC (mg/l)
10
1
0.1
Median=0.50 mg/L TN
TP EMC (mg/l)
10
1
0.1
0.01
0.001
Median=0.005 mg/L TP
TSS EMC (mg/l)
10000
1000
100
10
1
0.1
Median=3 mg/L TSS
7/6/2009
8/25/2009
10/14/2009
12/3/2009
1/22/2010
3/13/2010
5/2/2010
6/21/2010
8/10/2010
9/29/2010
11/18/2010
Effluent
Pickering Brook
Influent (36")

# Nutrient cycling

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# Phosphorous is typically in 3 forms:

- **Soluble Reactive Phosphorous.** SRP usually consists largely of the inorganic orthophosphate ($PO_4$) form of phosphorous. Measurements of orthophosphate are commonly used to quantify SP.
- **Soluble Unreactive or Soluble Organic Phosphorous.** SUP are organic forms of phosphorous and chains of inorganic phosphorous molecules termed polyphosphates.
- **Particulate Phosphorous.** PP contains all material, inorganic and organic, particulate and colloidal, that is captured on a 0.45-micron membrane filter.

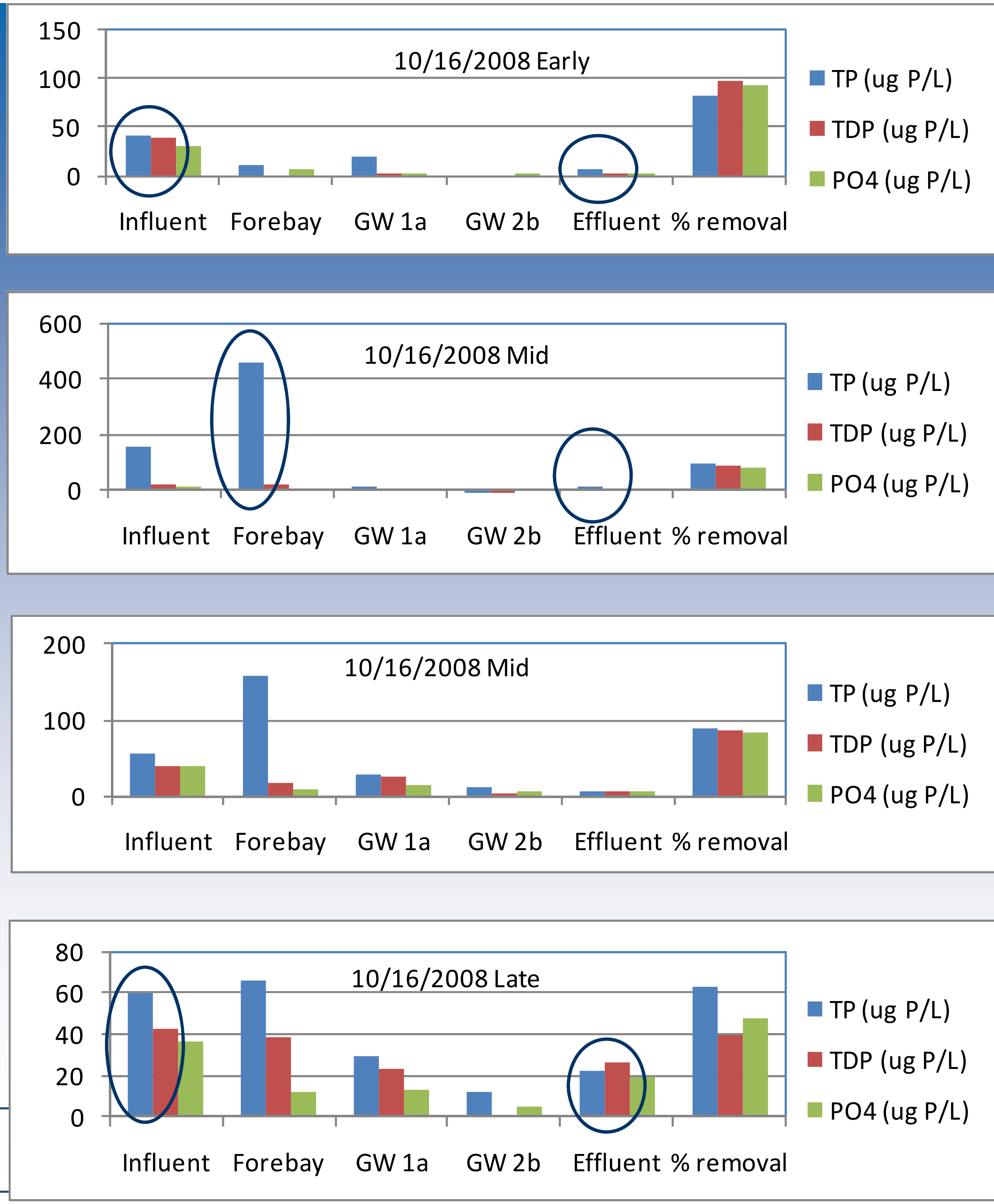
SRP +SUP= soluble phosphorous (SP)

SP+PP=total phosphorous (TP)

PO4 + SUP+PP=TP

# PHOSPHOROUS

Concentration ug/L



# Nitrogen in Stormwater Water

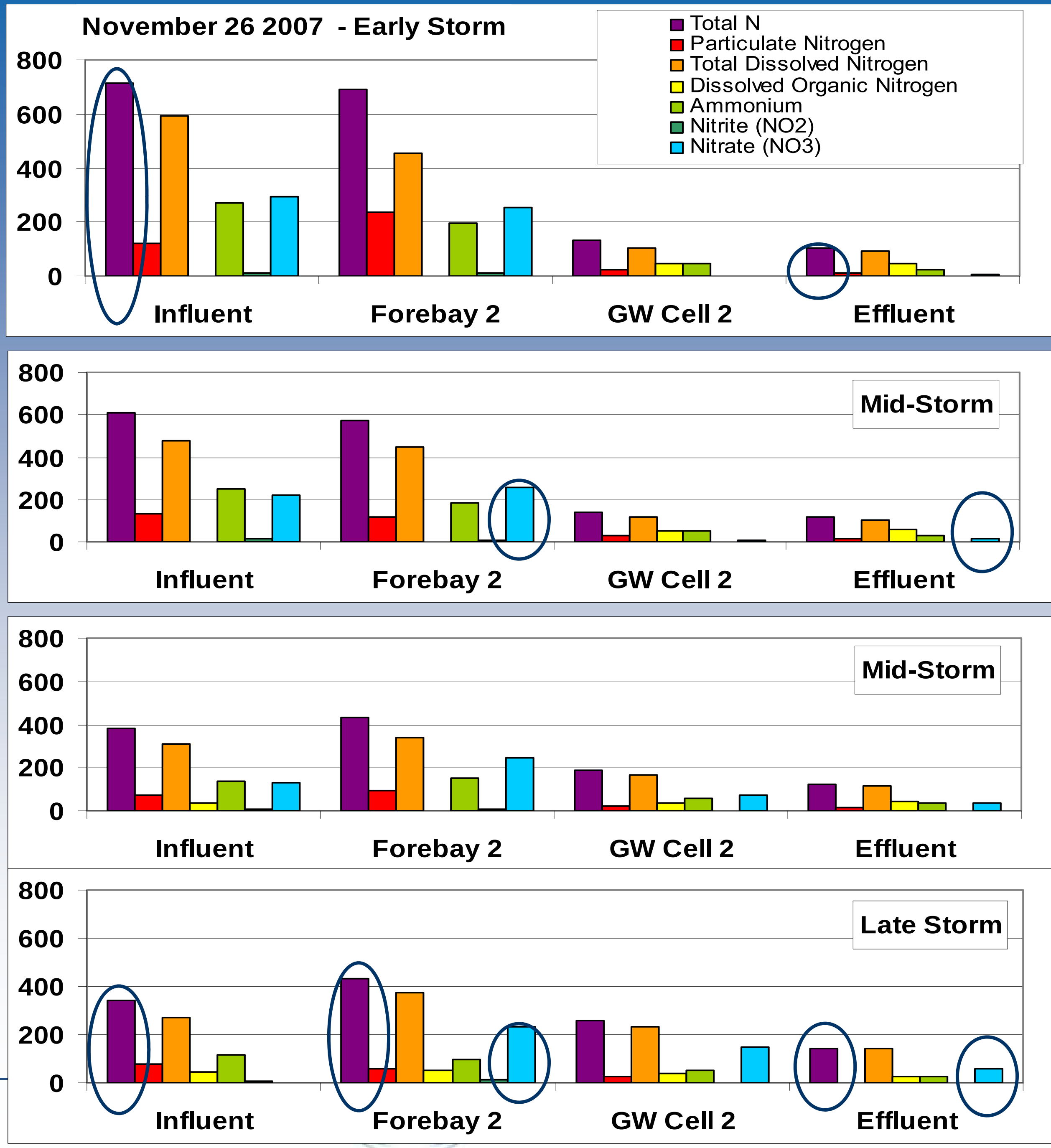
- Systems must be vegetated, sedimentation plays a minor role
- Biologically-mediated conversion processes, whether aerobic or anaerobic. Microbial decomposition of organic matter produces reduced $NH_3$ which is treated commonly through biological oxidation (nitrified) to $NO_2$/$NO_3$ and then treated by biological reduction anaerobically to $N_2$

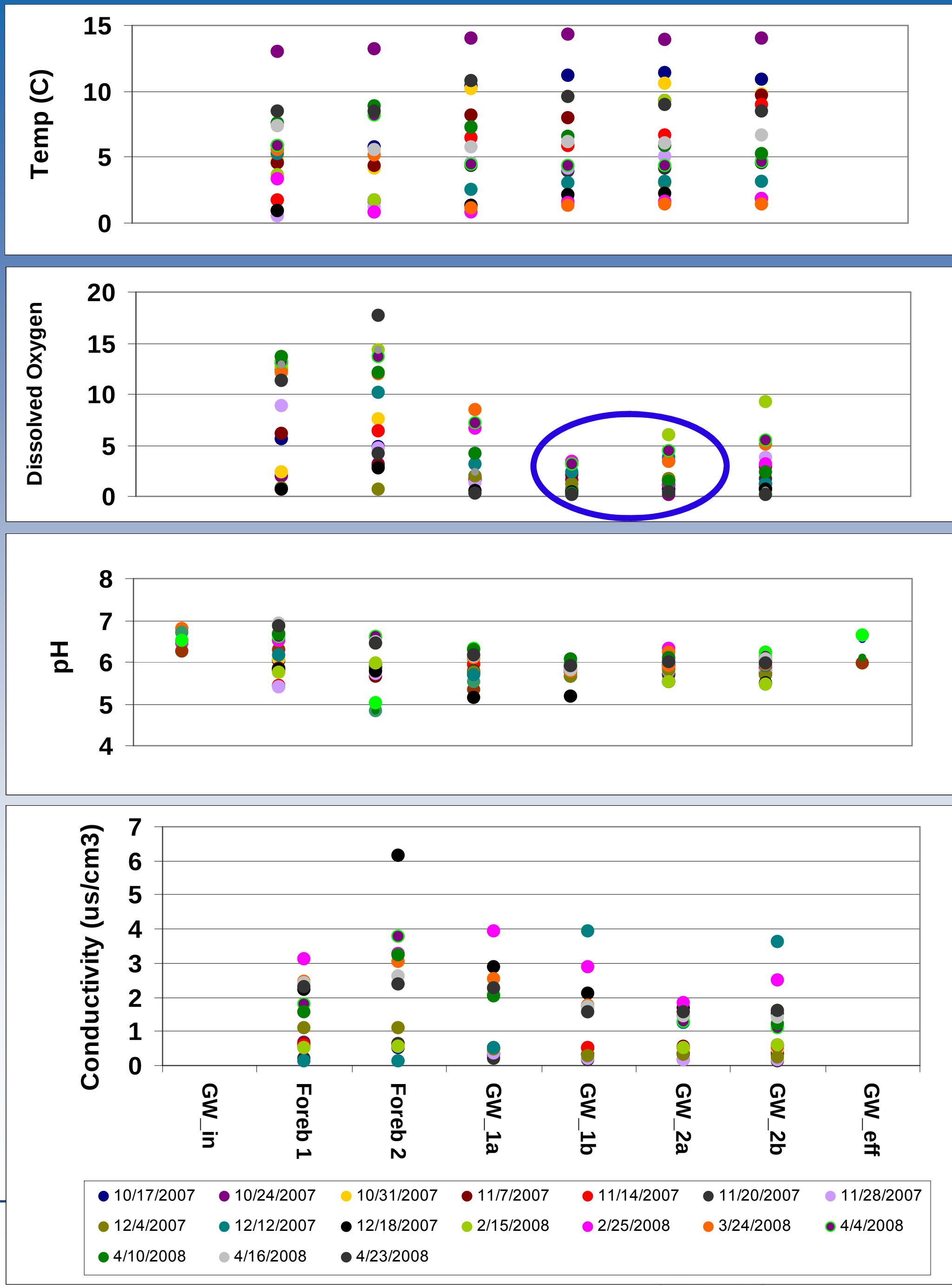
Organic N= TKN

TN = Organic N+$NH_3$+$NH_4$+$NO_2$+$NO_3$

# NITROGEN

Concentration ug/L





Temp (C)
15
10
5
0
Dissolved Oxygen
20
15
10
5
0
pH
8
7
6
5
4
Conductivity (us/cm3)
7
6
5
4
3
2
1
0
GW_in
Foreb 1
Foreb 2
GW_1a
GW_1b
GW_2a
GW_2b
GW_eff
10/17/2007
10/24/2007
10/31/2007
11/7/2007
11/14/2007
11/20/2007
11/28/2007
12/4/2007
12/12/2007
12/18/2007
2/15/2008
2/25/2008
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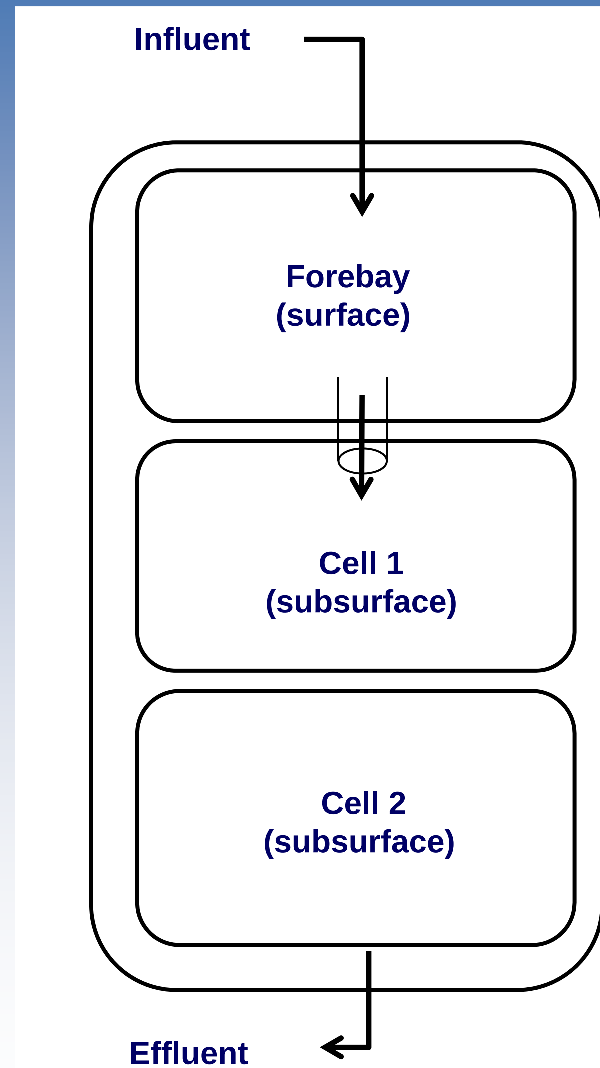
4/4/2008
4/10/2008
4/16/2008
4/23/2008

Influent
Forebay
(surface)
Cell 1
(subsurface)
Cell 2
(subsurface)
Effluent

# Thermal Performance

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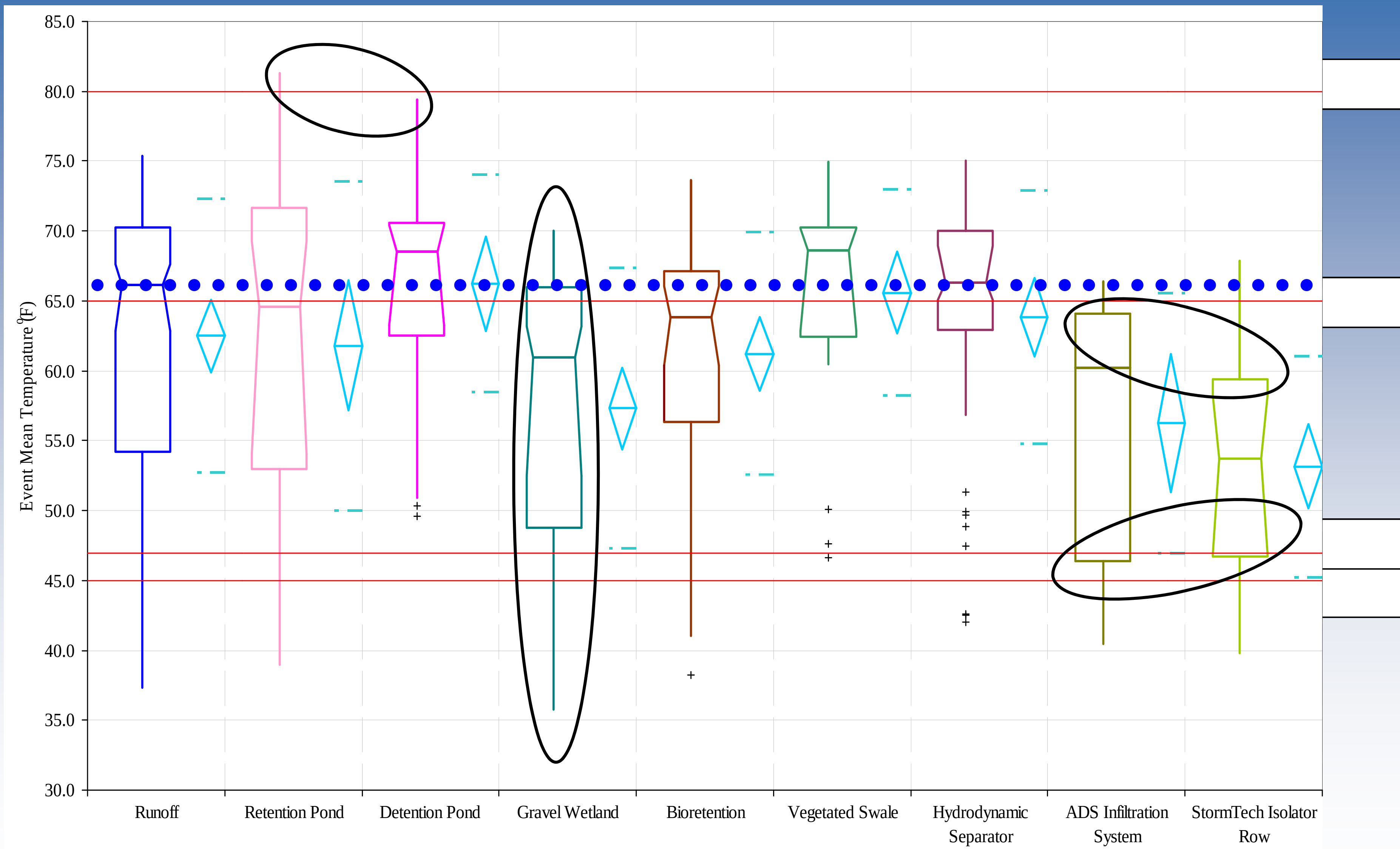
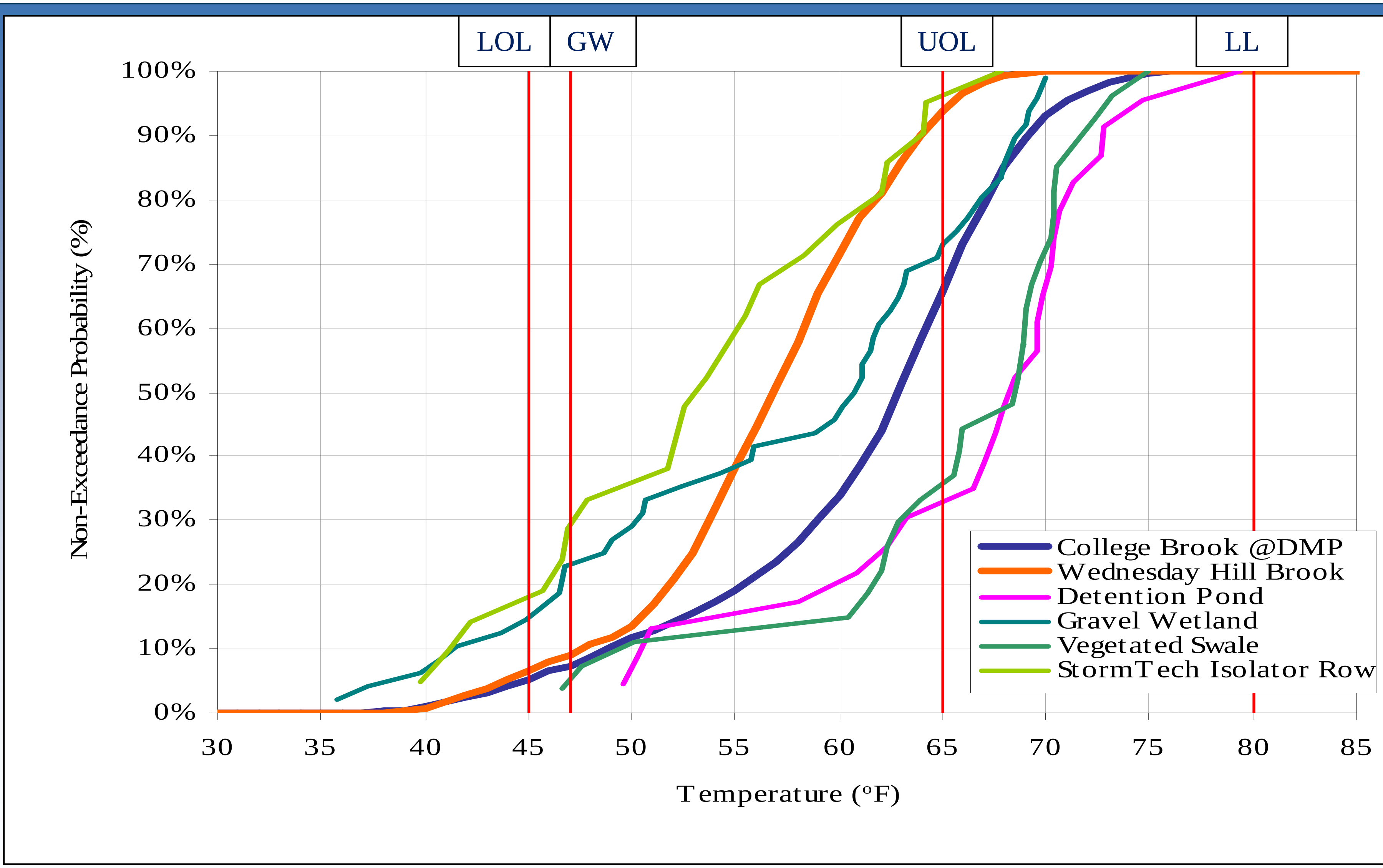
# Summer Quartile Assessment



# Summer Natural Streams



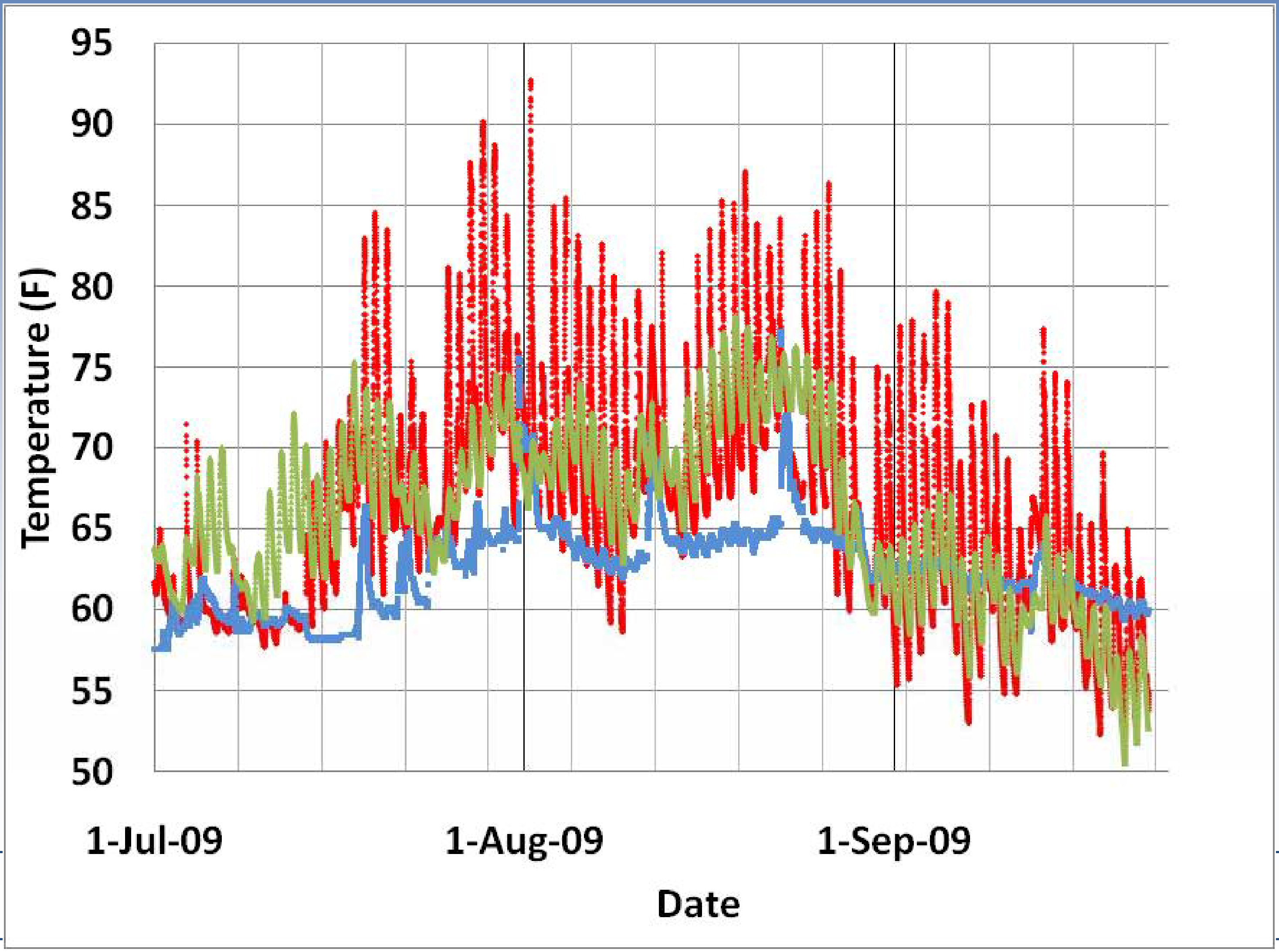
# Results

| Annual Assessments | | Runoff | Retention Pond | Detention Pond | Gravel Wetland | Bioretention | Vegetated Swale | HDS | ADS | STIR |
|---|---|---|---|---|---|---|---|---|---|---|
| EMT (°F) | Median | 52.4 | 48.1 | 52.8 | 47.3 | 51.8 | 57.3 | 56.6 | 49.2 | 47.6 |
| | Mean | 53.5 | 50.9 | 52.3 | 48.7 | 51.9 | 54.8 | 54.1 | 51.5 | 49.0 |
| | Standard Deviation | 12.7 | 14.6 | 15.1 | 12.0 | 13.1 | 12.6 | 13.6 | 9.7 | 9.2 |
| | Maximum | 75.4 | 81.3 | 79.4 | 70.0 | 73.7 | 75.0 | 75.0 | 66.4 | 67.8 |
| % Non-Exceedance UOL (65°F) | | 72.5% | 79.0% | 71.5% | 87.0% | 78.0% | 72.5% | 65.0% | 95.0% | 98.5% |

| Summer Assessments | | Runoff | Retention Pond | Detention Pond | Gravel Wetland | Bioretention | Vegetated Swale | HDS | ADS | STIR |
|---|---|---|---|---|---|---|---|---|---|---|
| EMT (°F) | Median | 66.2 | 64.6 | 68.6 | 60.9 | 63.9 | 68.6 | 66.3 | 60.3 | 53.7 |
| | Mean | 62.5 | 61.8 | 66.3 | 57.3 | 61.2 | 65.6 | 63.8 | 56.3 | 53.2 |
| | Standard Deviation | 9.8 | 11.8 | 7.8 | 10.1 | 8.7 | 7.3 | 9.1 | 9.3 | 7.9 |
| Mean July Temperatures (°F) | | 67.1 | 77.9 | 72.2 | 66.0 | 67.7 | 70.3 | 69.0 | 63.4 | 58.5 |
| % Non-Exceedance UOL (65°F) | | 42.0% | 56.0% | 37.0% | 73.0% | 58.5% | 35.0% | 34.0% | 91.0% | 96.0% |

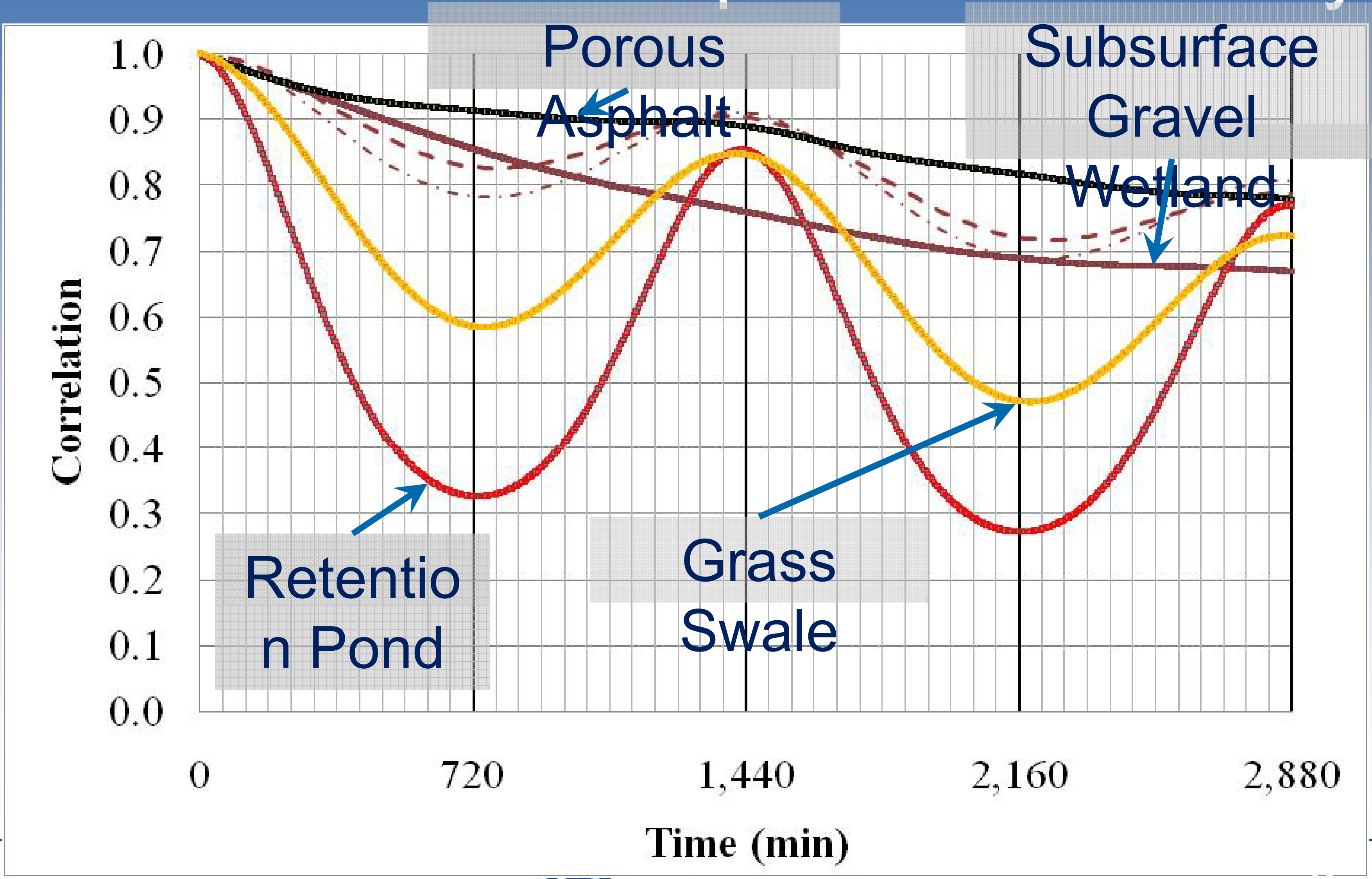
# Time Series Characteristics

Subsurface Gravel Wetland (blue) Retention Pond (red)
Caldwell Brook (green)



# So When Stormwater Flows Into These Systems……Is it Memory Compatible?

# 2009 Summer Temperatures – 2 days

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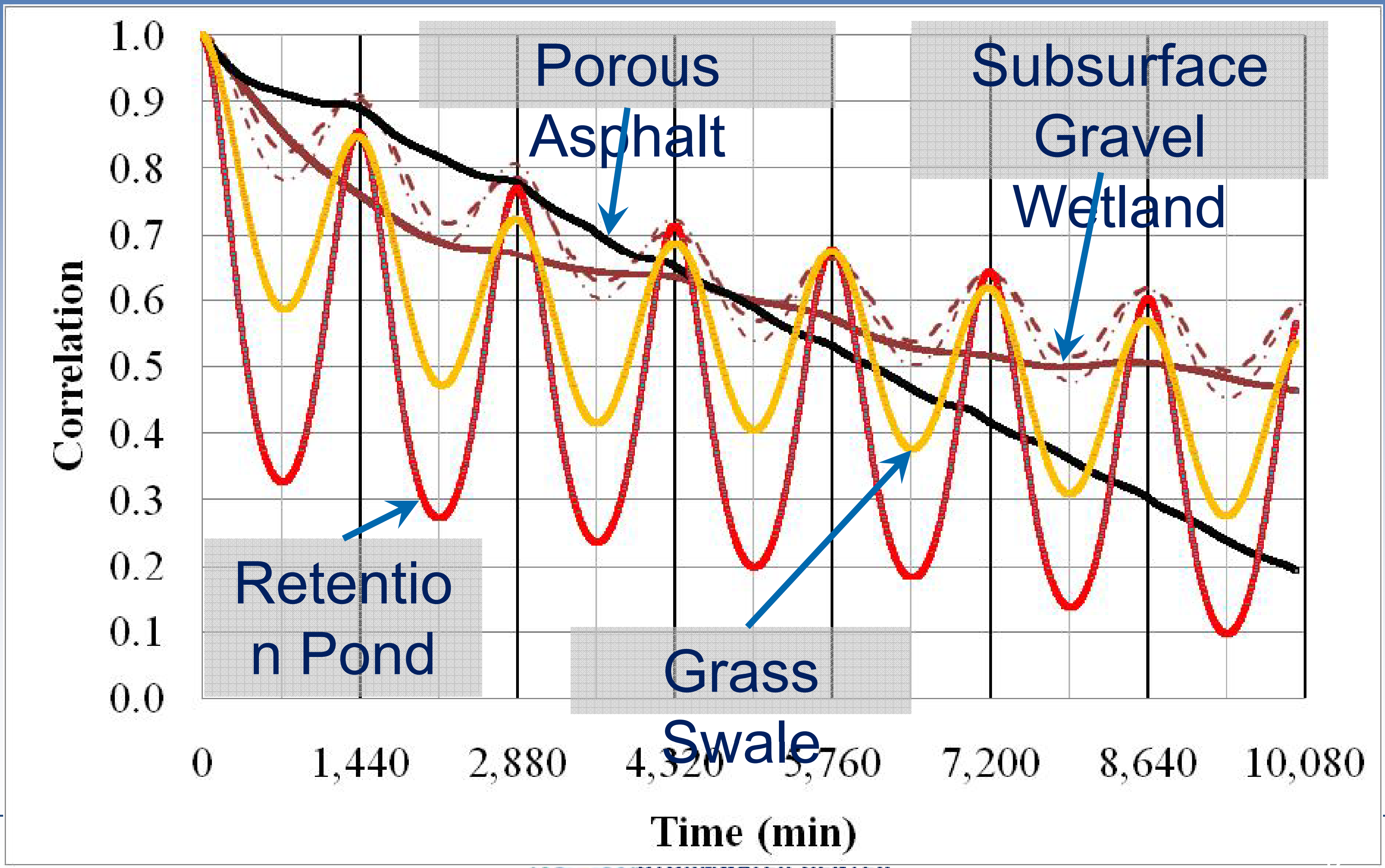
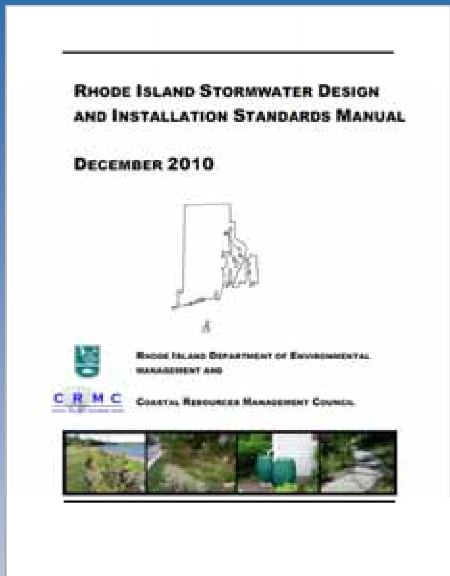
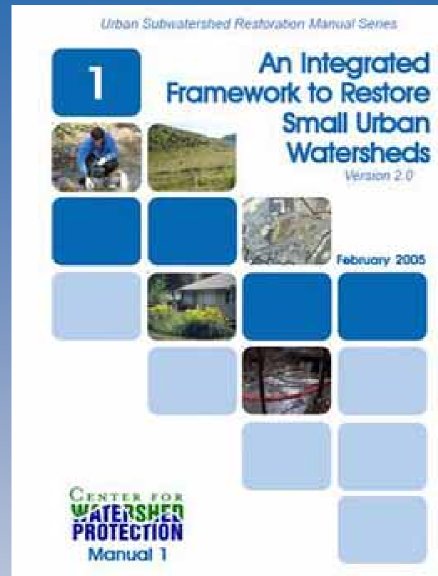
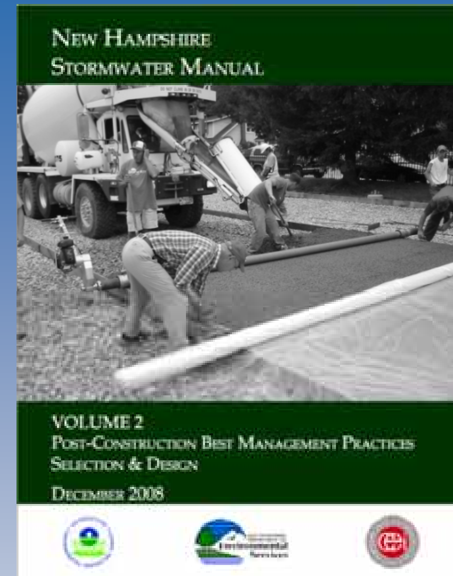
# 2009 Summer Temperatures – 7 days

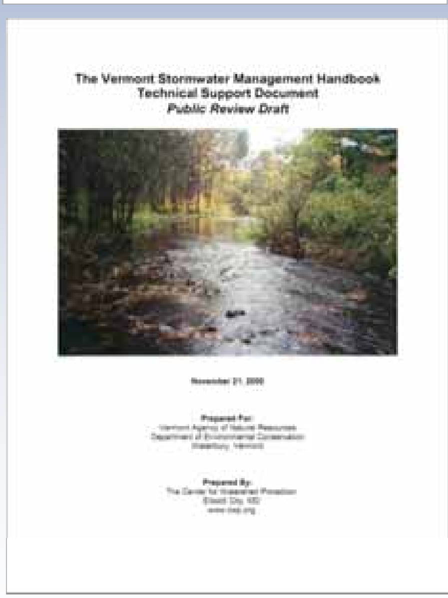


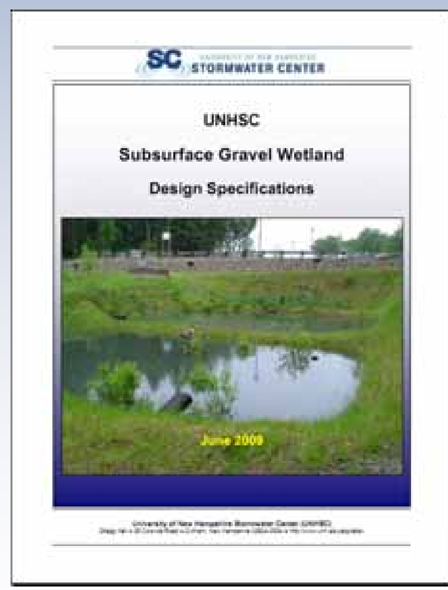
# System Design
# and
# Sizing


Rhode Island Stormwater Design and Installation Standards Manual
December 2010
Rhode Island Department of Environmental Management and
C R M C
Coastal Resources Management Council


Urban Subwatershed Restoration Manual Series
1
An Integrated Framework to Restore Small Urban Watersheds
Version 2.0
February 2005
Center for Watershed Protection
Manual 1


New Hampshire Stormwater Manual
Volume 2
Post-Construction Best Management Practices Selection & Design
December 2008


The Vermont Stormwater Management Handbook
Technical Support Document
Public Review Draft


SC Stormwater Center
UNHSC
Subsurface Gravel Wetland
Design Specifications
June 2009


New Jersey
Stormwater
Best Management Practices Manual
New Jersey Department of Environmental Protection
Division of Watershed Management

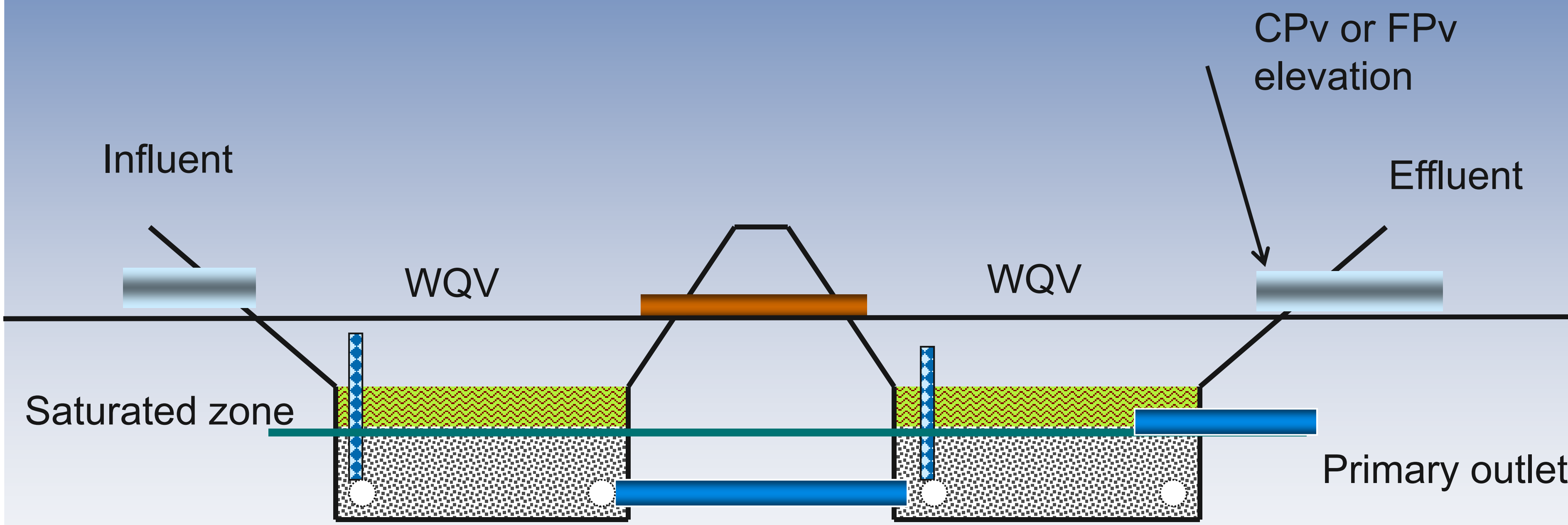
# Design Criteria

- Water Quality Volume (WQv)
- Channel Protection Volume (Q2)
- Extreme Storm Volume (Q10)

# WQV

- WQV is a static sizing criteria meaning it is the calculated volume resulting from the WQ storm depth (1 inch in 24 hrs) across the drainage area ( 1 acre parking lot = 3,300 cf)
- In this case the system needs to provide storage and treatment for the WQV as if it were delivered instantaneously.

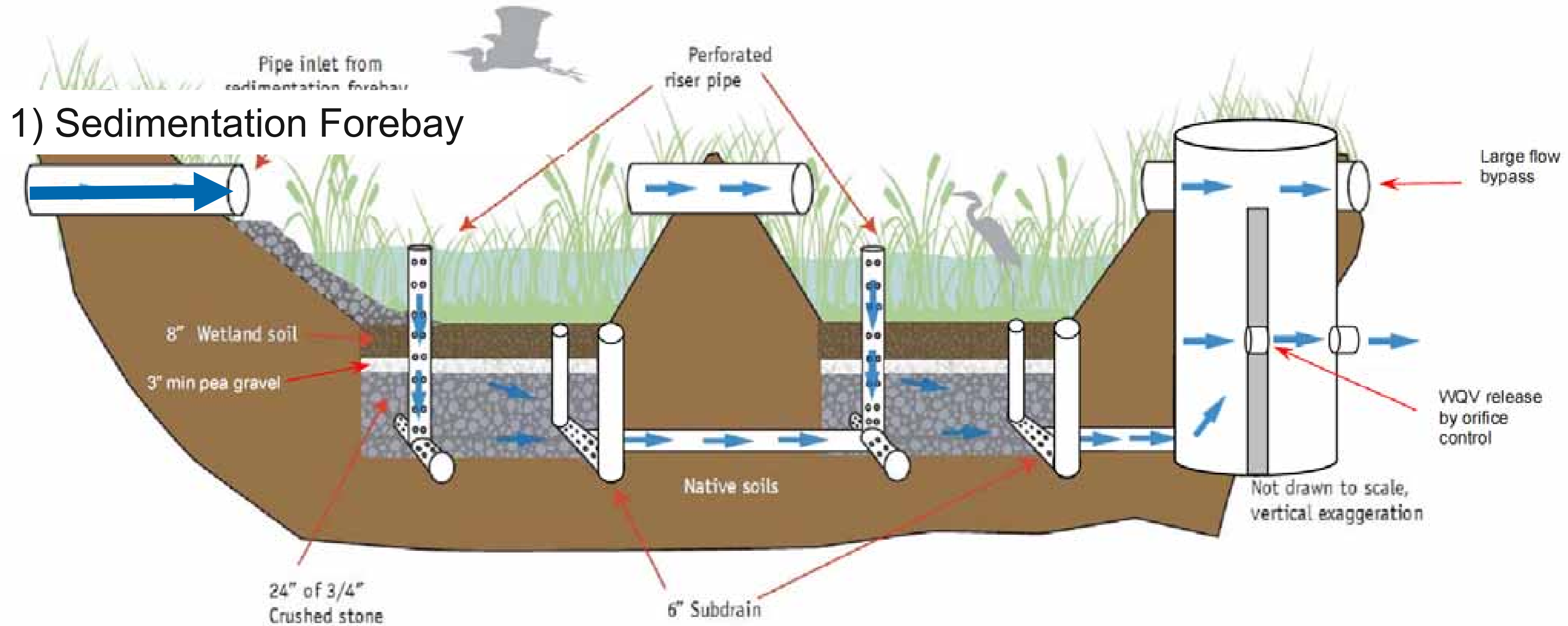
# Generic Cross-Section



# Critical Design Elements

1. Pretreatment
2. Two Treatment Cells.
3. Flow path
4. Geotextile usage
5. Wetland soils
6. Subgrade soils
7. Liners
8. Materials
9. Inlet Structures
10. Outlet Structure

# Subsurface Gravel Wetland

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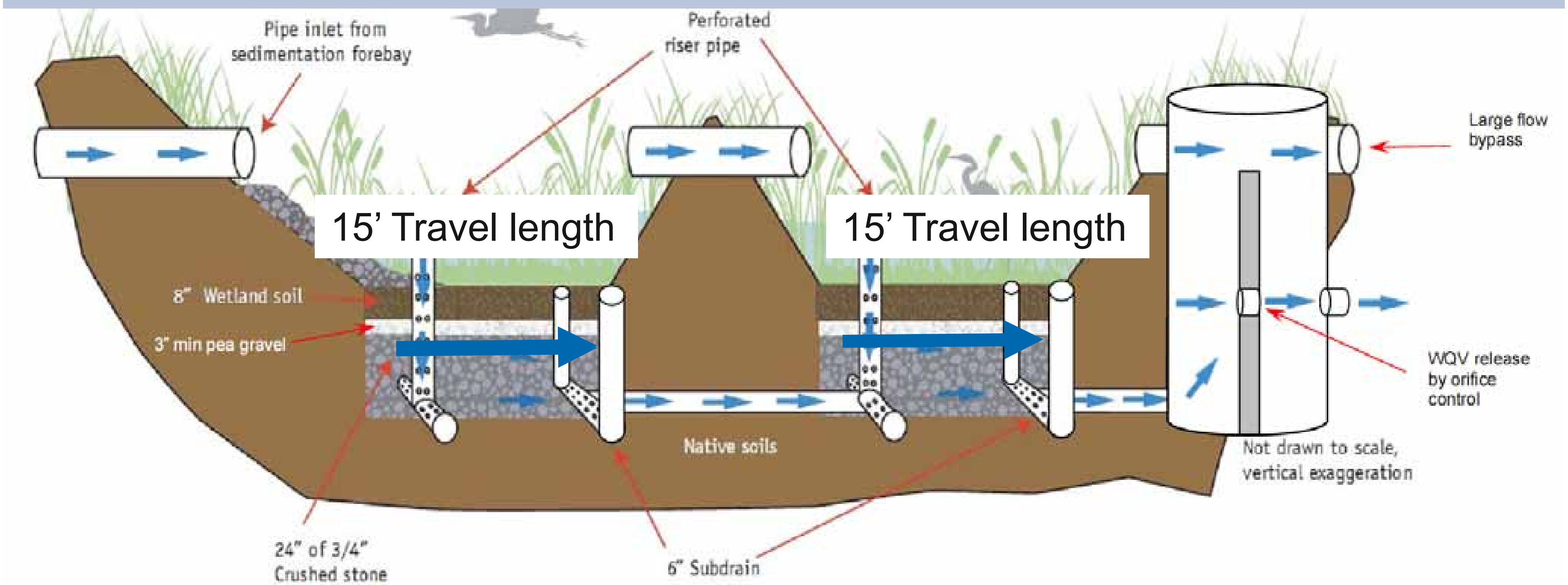
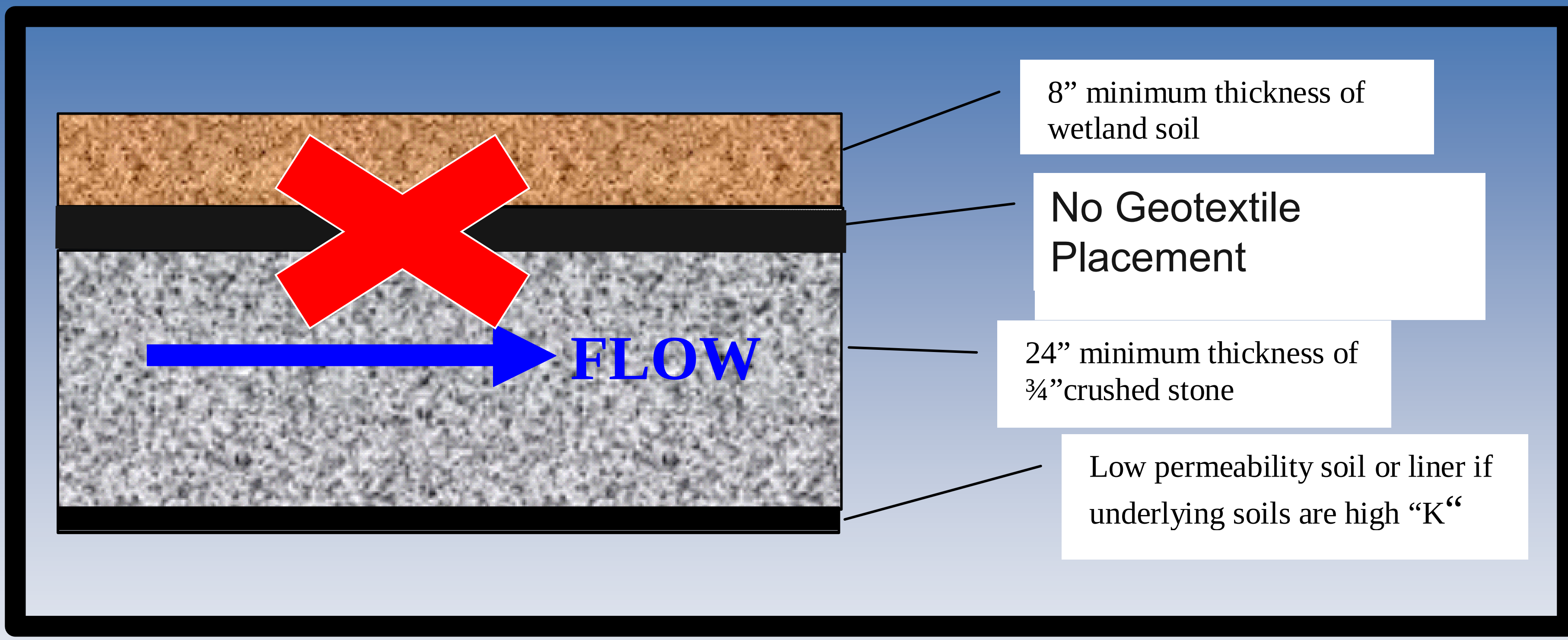
# Flow Path

- Minimum flow path length through the gravel should be 15 ft per cell, 30 ft total
- Flow path is horizontal and distinct from most biofiltration



# Geotextiles




- No Geotextile between soil and crushed stone, in replace use intermediate setting bed
- Do not use geotextiles between the horizontal layers of this system as they will clog due to fines and may restrict root growth.

# Wetland Soil

- 8 in. (20 cm) minimum thickness of a wetland soil as the top layer.
- This layer is leveled (constructed with a surface slope of zero).
- The surface infiltration rates of the gravel wetland soil should be similar to a low hydraulic conductivity wetland soil (0.1-0.01 ft/day = 3.5 x $10^{-5}$ cm/sec to 3.5 x $10^{-6}$ cm/sec)).

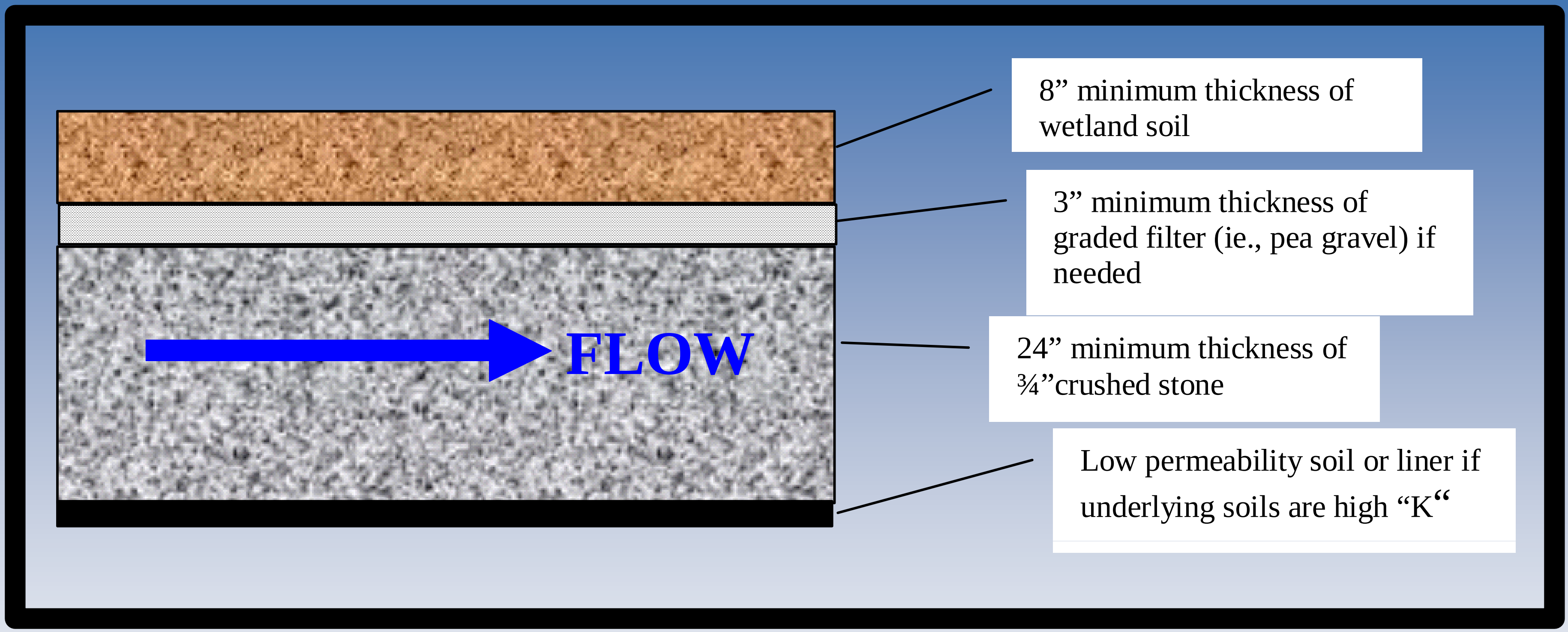
# Wetland Soil

- This soil can be manufactured using existing topsoil, and compost, or sand, and some fine soils to blend to a high % organic matter content soil (>15% organic matter).
- Avoid using clay contents in excess of 15% because of potential migration of fines into subsurface gravel layer.

$$D_{15,\ COARSE\ \ SUBLAYER} \leq 5\ X\ D_{85,\ SETTING\ \ BED}$$

$$D_{50,\ COARSE\ \ SUBLAYER} \leq 25\ X\ D_{50,\ SETTING\ \ BED}$$

# Subgrade Soils



# Subgrade Soils

- Underlying soils should have low permeability to maintain driving head and risk of groundwater contamination
- Hydraulic conductivity ≤ 0.03 ft/day
- If low permeability soils are present, use a compacted soil or HDPE liner.

# Liners

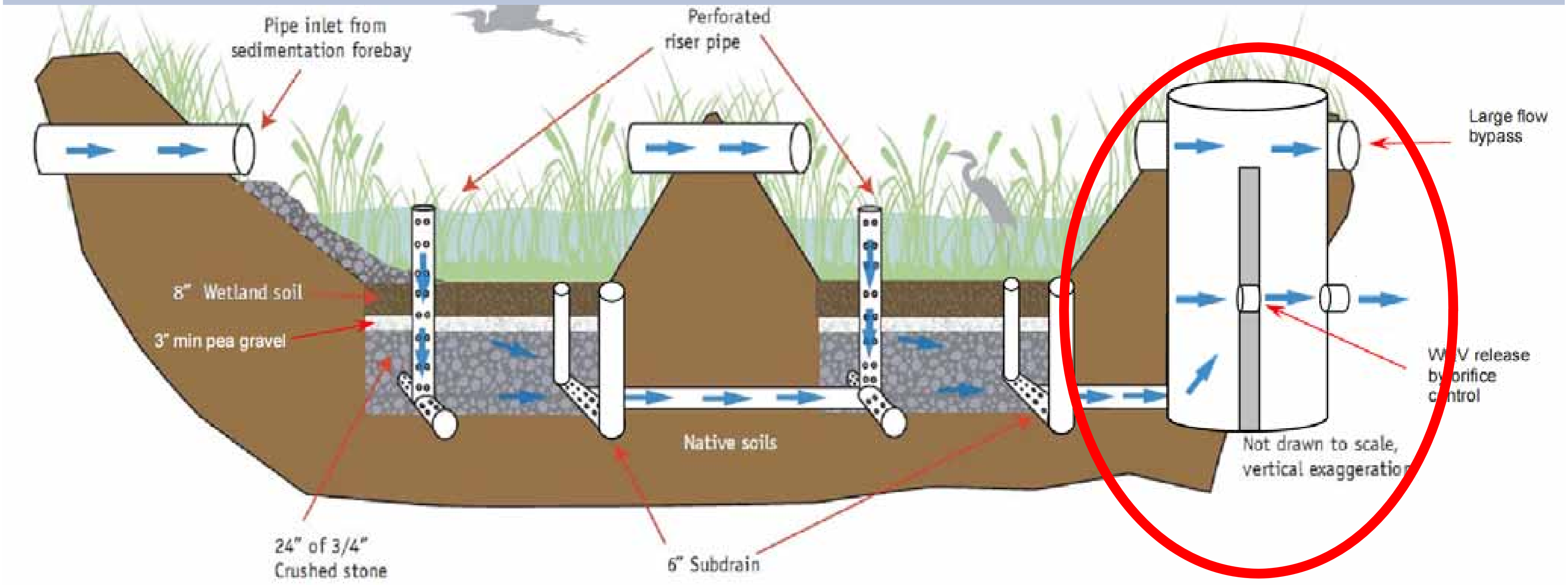
- Federal guidelines regulate groundwater protection standards.
- Liners can be used for sites where the infiltration is a concern (eg. high water table, bedrock karst sites and hot spots where hazardous materials may be handled).
- The use of Liners will preserve water quality through detention and filtration and will limit any infiltration.
- Liners can be made from HSG 'D' soils, HDPE, or clay

# Reservoir Course

- 3 in. (8 cm) minimum thickness of an intermediate setting bed layer of a graded aggregate filter overtop the reservoir course
- Prevent the wetland soil from moving down into the gravel sub-layer through soil piping
- Material compatibility between layers needs to be evaluated.
- Reservoir course is constructed of ~0.75" angular stone (similar to ASTM#57)

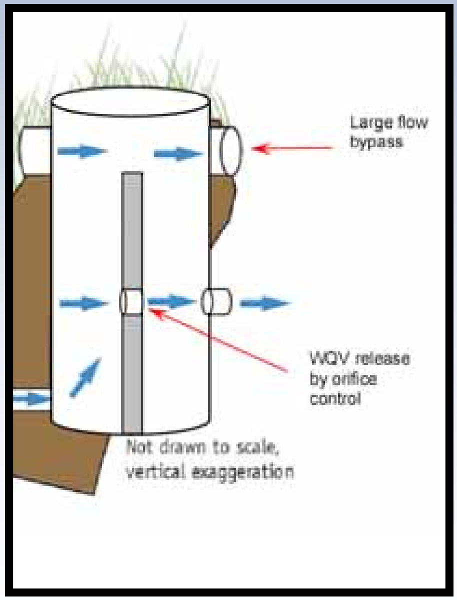
# Outlet Structure

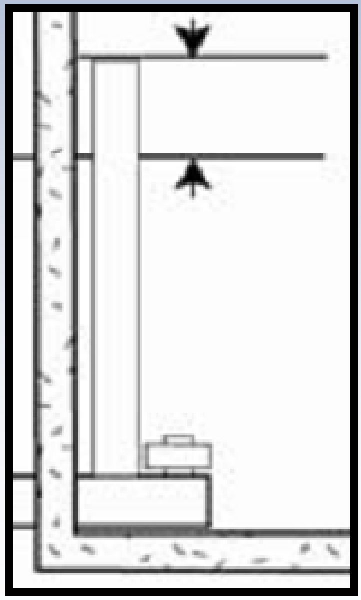
- Many options
- All will have WQV release and highflow bypass
- May include drainplug for maintenance

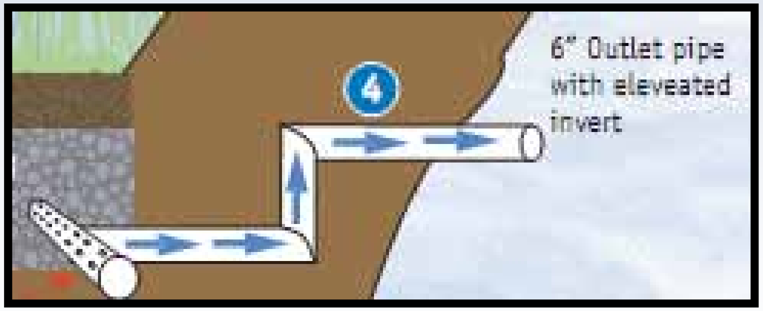


# Outlet Structure

- Outlet Structure Options vary
  - Precast structure with weir wall
  - T-fitting with valve
  - Upturned elbow



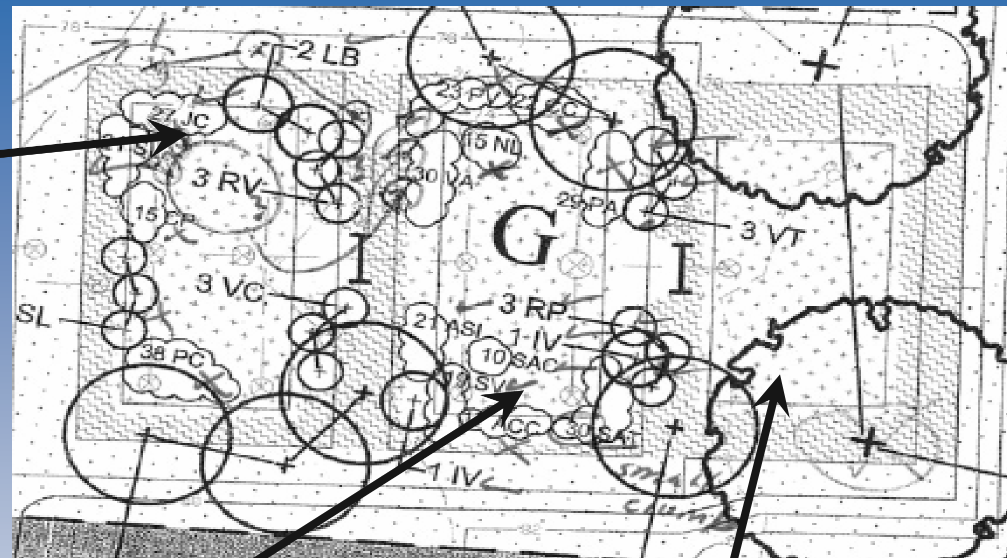


# Wetland Vegetation

- Used New England Wetmix (wetland seed mix) from New England Wetland Plants Application Rate: 1 LB/2500 SQ. FT. (18 LBS/ACRE as a wet meadow seeding)
- http://www.newp.com
- Price: $125.00/LB**
- Gravel wetland – mixed wetland grasses, reeds, herbaceous plants and shrubs growing vigorously. 100% cover, except for open water in forebay. Very few upland plants. Healthy, diverse wetland system.

# Gravel Wetland

Sagittaria, Cattail, Juncus, grasses, areas with standing water




Bullrush (scirpus), aster, grasses, no standing water

Rush (juncus), cattail, grasses, open water

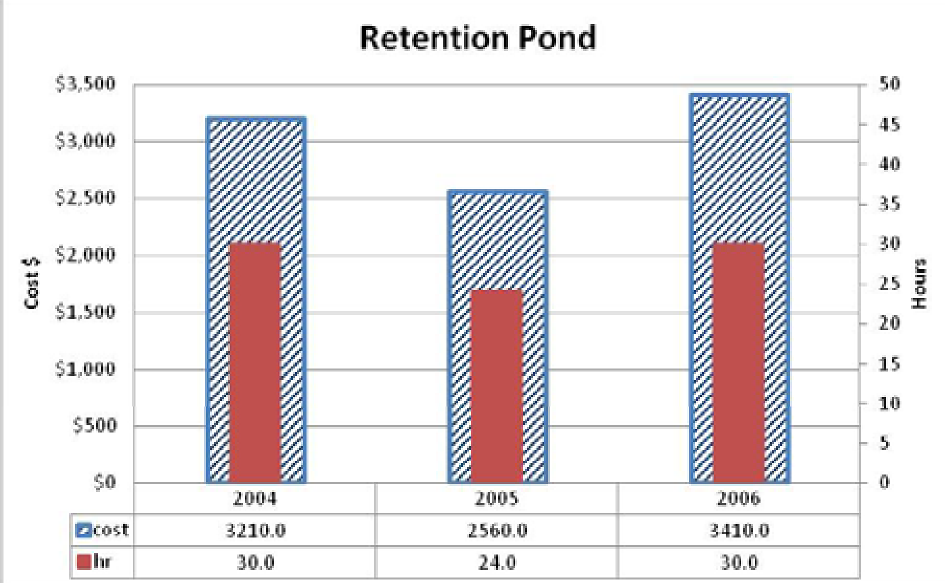
# UNH SC – General Wetland Condition

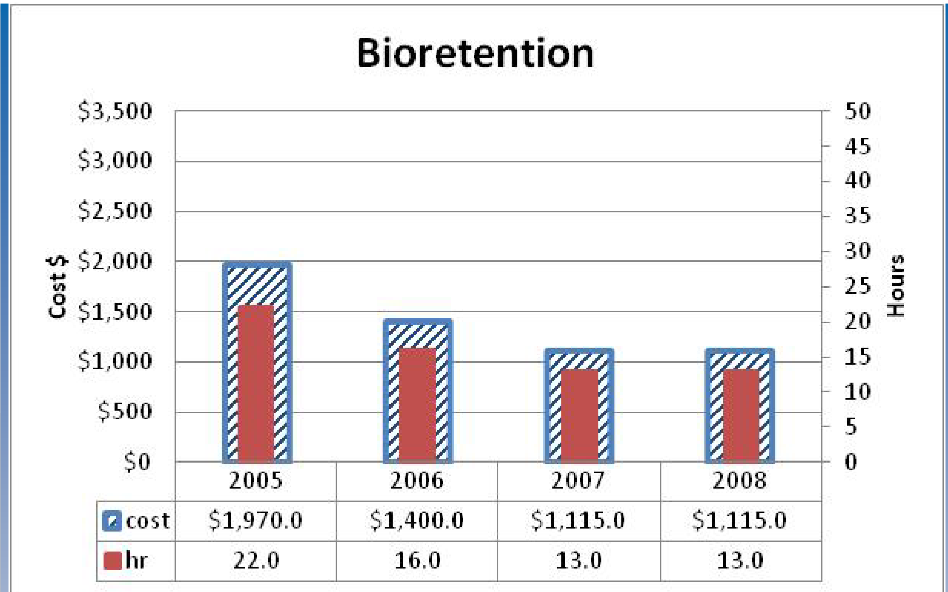
- 53% of the planted species are still present (in areas that have not been re-constructed).
- Trees and shrubs had a high survival.
- Emergent obligate wetland species (e.g water lily, pickerelweed) survival was very low.
- All areas with standing water populated by Typha (cattail).
- No Phragmites, some Purple Loosestrife removed.
- Predominantly emergent marsh/wet meadow species.
- Some vertebrate wildlife species present; frogs and heron.

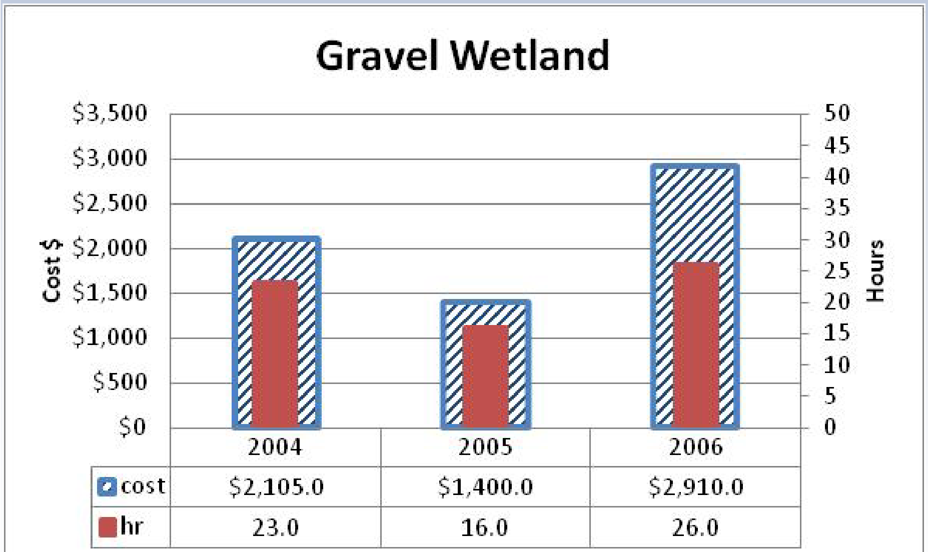
# Inspection and Maintenance

| REACTIVE | PERIODIC |
| --- | --- |
| Episodic maintenance<br>Cheap in short term<br>Expensive in long term<br>Most property damage | Can be expensive and wasteful<br>Need statistics<br>Simple administration |
| **PREDICTIVE** | **PROACTIVE** |
| Scientific basis<br>Cost-effective<br>Not applicable everywhere<br>Administration more difficult | Can be cost-effective<br>Expensive if overused<br>Can have institutional implications |

Reese, A.J., Presler, H.H., 2005


Retention Pond
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Cost $
50
45
40
35
30
25
20
15
10
5
0
Hours
2004
2005
2006
cost 3210.0 2560.0 3410.0
hr 30.0 24.0 30.0


Bioretention
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Cost $
50
45
40
35
30
25
20
15
10
5
0
Hours
2005
2006
2007
2008
cost $1,970.0 $1,400.0 $1,115.0 $1,115.0
hr 22.0 16.0 13.0 13.0


Gravel Wetland
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Cost $
50
45
40
35
30
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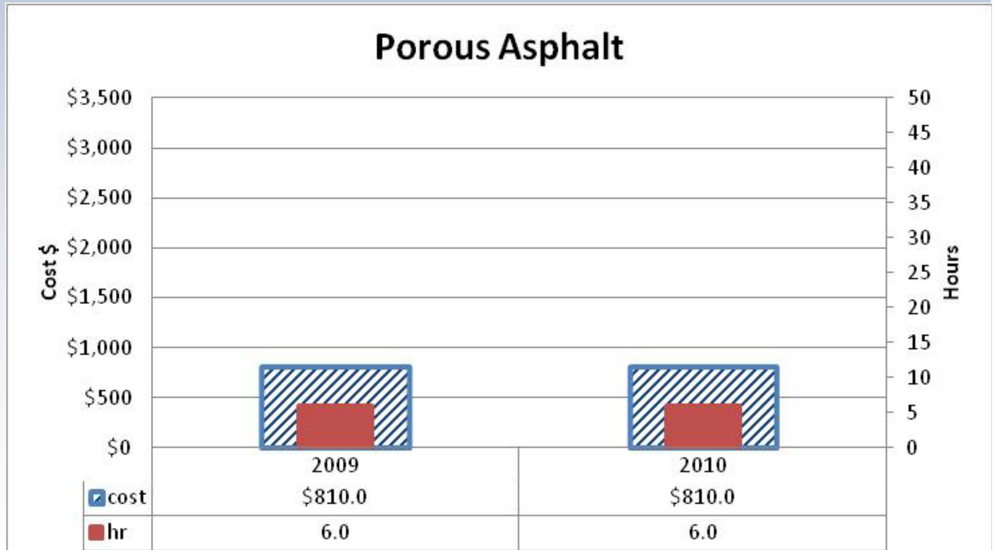
Hours
2004
2005
2006
cost $2,105.0 $1,400.0 $2,910.0
hr 23.0 16.0 26.0


Porous Asphalt
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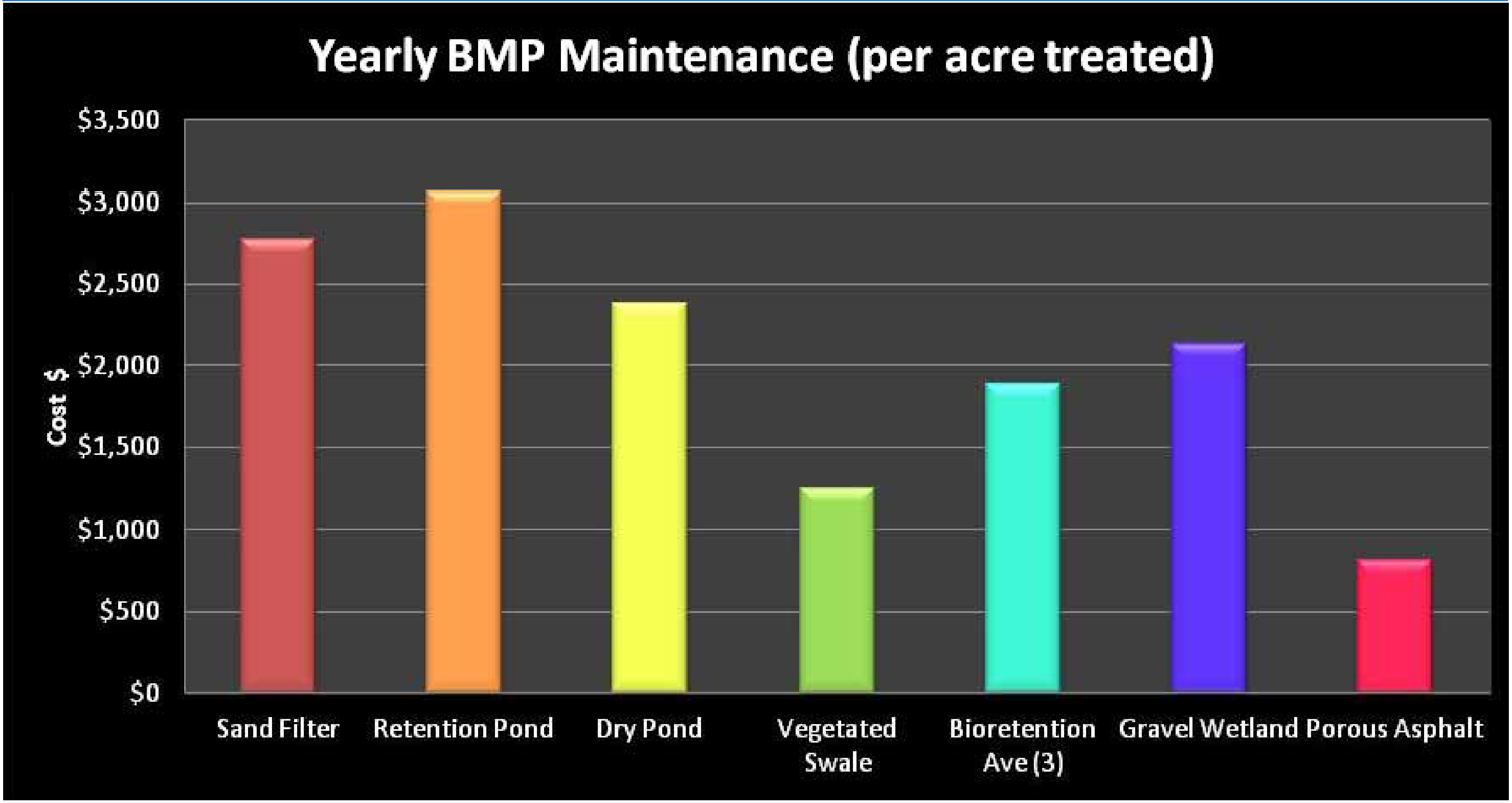
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Cost $
50
45
40
35
30
25
20
15
10
5
0
Hours
2009
2010
cost $810.0 $810.0
hr 6.0 6.0

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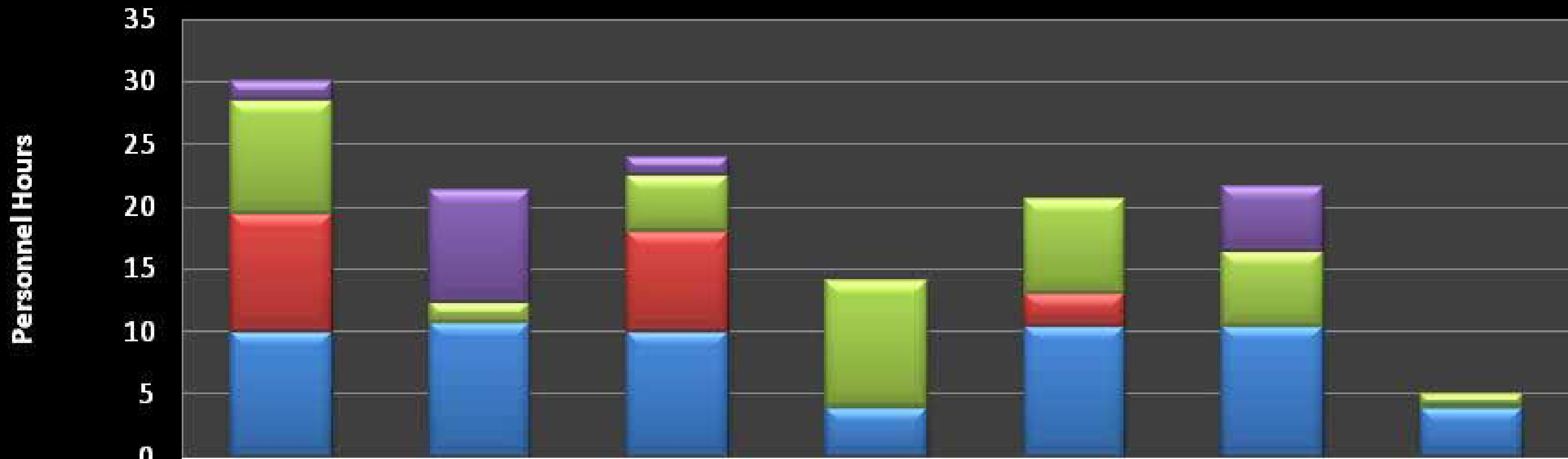
## BMP Maintenance/acre/yr by Catagory




| | Sand Filter | Retention Pond | Dry Pond | Vegetated Swale | Bioretention (3) | Gravel Wetland | Porous Asphalt |
|---|---|---|---|---|---|---|---|
| Reactive | 1.5 | 9 | 1.5 | 0 | 0 | 5 | 0 |
| Proactive | 9 | 2 | 4.5 | 10 | 8 | 6 | 1 |
| Predictive | 9.5 | 0 | 8 | 0 | 3 | 0 | 0 |
| Periodic | 10 | 11 | 10 | 4 | 10 | 10 | 4 |

# 4 - yr Forebay Maintenance - June 2008

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# Current 3-yr Maintenance Plan

# Maintenance

- The forebay to the gravel wetland, and probably all stormwater systems may become a source of contamination as the system ages—maintenance is essential

- Improved forebay designs would include a deeper pool of water in excess of a meter, or a deep sump catch basin or proprietary treatment device for removal of solids.

# Maintenance

- Sediments and plant debris stored in the forebay may be re-suspended and released in subsequent storms. Routine maintenance is an important component in maintaining performance—2-3 year interval.

# Materials and Installation Cost

| Technology | Cost: $/Acre IC |
| --- | --- |
| Vegetated Swale | $ 11,200.00 |
| Retention Pond | $ 13,700.00 |
| Gravel Wetland | $ 22,300.00 |
| Bioretention | 15,000 - 25,000 |
| HDPE Chamber | $ 34,000.00 |

# Greenland Case Study

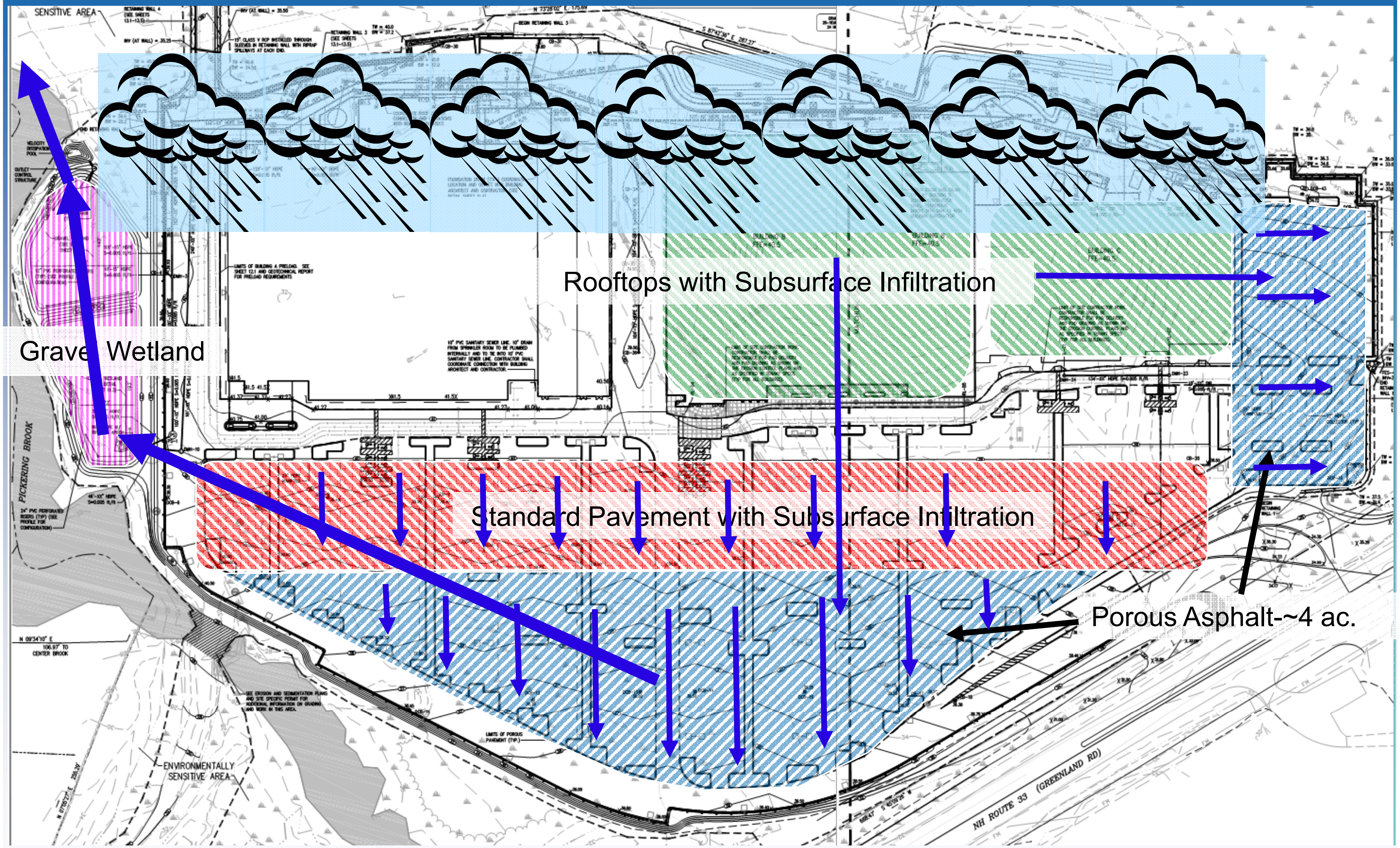
# CASE STUDY: Greenland Meadows

**Packard Development, Conservation Law Foundation, UNHSC (2005- Present)**

- Protection of impaired waters—Pickering Brook
- >15,000 Average Daily Traffic count

Involves the use:

- daily street vacuuming
- a porous asphalt parking lot
- subsurface infiltration of rooftop runoff
- a gravel wetland
- Combined as a treatment train




Entire site is treated by filtration, either porous pavement, subsurface infiltration, or gravel wetland,

or combination of methods



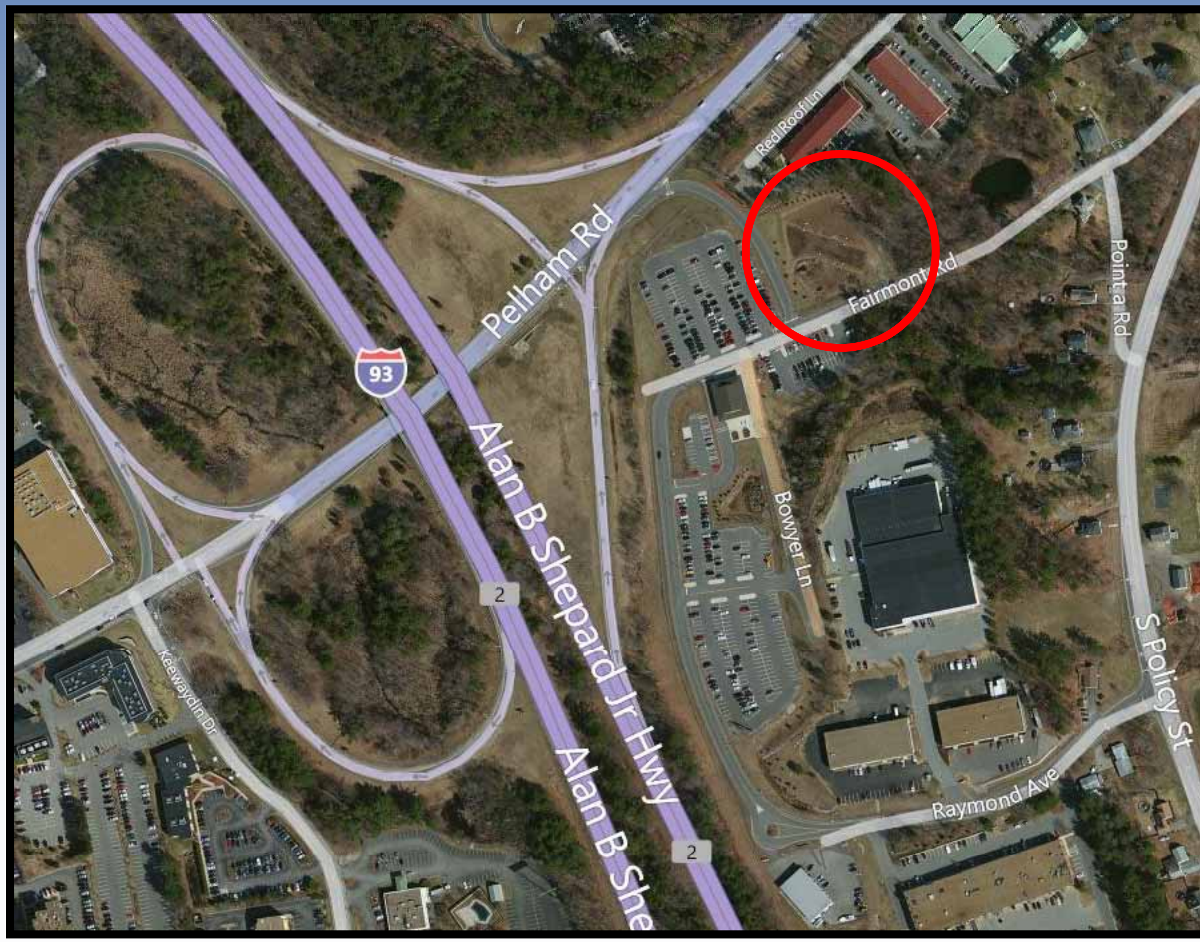

# 3 mos later

# 3 years later

# Discharge to Impaired Water

# TMDL Impaired Watershed

- NHDOT Exit 2 Park and Ride
- GW use for 401 WQ Certification
- Used widely by NHDOT on I-93 and Rt 16 Expansion



# NHDOT Install Exit 5

# Funding

Funding is provided by the Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET) whose mission is to support the scientific development of innovative technologies for understanding and reversing the impacts of coastal and estuarine contamination and degradation.